Designing Interactions for Multi-touch Spherical Displays to Support Collaborative Learning in Museums

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ABSTRACT

Spherical displays are increasingly being used to present global data visualizations to support Earth science education in informal learning settings such as museums. However, most spherical displays deployed to date either support no interactivity or interaction only via an external touchscreen. Only recently have spherical displays become commercially available that can support multi-touch gesture interactivity. Family groups visiting museums can gather around these displays to collaboratively explore global science datasets simultaneously. However, the use of multi-touch spherical displays as an educational tool is relatively new and a deeper knowledge of how to design interactions for spherical touch surfaces to support collaborative learning has not been explored yet. Through my thesis work, I will explore how to design gestural interactions for multi-touch spherical displays to support collaborative learning from interactive science data visualizations in museums.

CCS CONCEPTS

•Human-centered computing ~ Human-computer interaction (HCI) ~ Interaction devices ~ Touch screens

KEYWORDS

Multi-touch spherical displays, Collaborative learning, Touchscreen gestures, Museums.

1 Introduction

The National Oceanic and Atmospheric Administration's (NOAA) Environmental Literacy Program identifies that basic knowledge of Earth science concepts is vital to meet the environmental challenges of the 21st century [19]. As one way to support this call-to-action, museums are increasingly using spherical displays as an educational tool that enables family groups to openly explore and learn from data visualizations about Earth science [20]. Prior work comparing the impact of spherical versus flatscreen displays on helping learners understand Earth science concepts has found that spherical displays, which are a more faithful physical model of the Earth, outperformed flatscreen displays in terms of students' knowledge gains [8].

Based on the museum learning paradigm called *Active Prolonged Engagement* [3], allowing family groups to actively interact with the learning content using direct-touch gestures (as opposed to passively viewing it) has been shown to maximize user engagement and afford learning. However, most spherical displays deployed to date either support no interactivity or interaction only via an external touchscreen. Only recently have spherical displays become commercially available that can support multi-touch gesture interactivity [21]. However, the use of multi-touch spherical displays as an educational tool is relatively new and a deeper understanding of how to design multi-touch spherical display applications in this space has not been studied yet. Also, as people often visit museums in groups, allowing multiple learners to collaboratively learn at the same time is important when designing experiences for public spaces.

If interactions enabled by multi-touch spherical interfaces are not intuitive, learners' attention may shift towards understanding the interface rather than engaging with the educational content [12]. Thus, given the importance of using spherical displays for Earth science education, and a lack of research in the context of designing for these displays to support collaborative learning experiences, I propose to investigate this space. The primary objective of my thesis work is to **design and evaluate a multi-touch spherical application that allows family groups to collaboratively learn about Earth system science by interacting with large global data visualizations using natural gestures.** In my completed work, I have investigated users' gestural interaction preferences on spherical displays. In

my continued work, I am focusing on understanding groups' collaboration behaviors around multi-touch spherical displays to help design interactions for supporting collaborative learning.

2 Related Work

I provide a brief overview of prior work that others have done on multi-touch flatscreen displays for learning, as well as on designing interactions for multi-touch spherical displays.

2.1 Multi-touch Gesture Interactive Flatscreen Displays for Learning

Although multi-touch spherical displays have not yet been studied for educational purposes, my research takes inspiration from related work on educational flatscreen tabletop displays. Several studies focusing on science learning with flatscreen tabletops have established that touch interactions play a vital role in supporting group learning in both formal and informal learning settings [1,11]. Shaer et al. [11] explored tabletop interactions for classroom science learning and found that allowing groups to spatially manipulate and annotate the learning content using intuitive gestures supported group reflection during collaborative learning. Other prior work has explored the role gestural interactions play in affording engagement around tabletop displays, without considering learning. In one of my thesis advisor's prior work, Anthony et al. [1] conducted an observational study in a science museum and highlighted design implications for gestural interactions in the context of large flatscreen displays in public. For example, they recommend that designing simple gestural interactions would ensure that users are able to get engaged in science inquiry more quickly. Although these studies offer a solid foundation for understanding the role of gestural interactions in supporting learning around flatscreen tabletops, little is known about the extent to which these findings can be directly applied to spherical displays. My thesis explores the nature of gestural interactions learners of all ages will find intuitive when collaboratively exploring global data visualizations around multi-touch spherical displays.

2.2 Designing Interactions for Collaborative Learning Around Multi-Touch Spherical Displays

Much of the prior research on designing gestures for spherical displays has taken a designer-based approach (i.e., gestures designed by experts, not users) [15]. Benko et al. [2] developed the first multi-touch spherical display prototype and proposed a set of designer-defined touchscreen interactions, as well as interactions to facilitate collaboration. Since multi-touch spherical displays have only recently become commercially available [21], researchers have started to move out of the lab setting to provide recommendations for designing interactions for spherical displays based on in-the-wild studies. Williamson et al. [21] ran a study with a multi-touch spherical display in a public setting and found that providing more interaction styles encouraged users to explore more features and consequently increased dwell time.

While prior work has studied designing interaction for spherical displays, most of the prototypes tested in the above studies used expert-designed gestures rather than being informed by users' mental models. However, for real-world use of new platforms, designer-defined gestures are less discoverable for users than gestures designed by end-users [6]. Furthermore, designing interactions for group learning on spherical displays is subject to multiple open interaction design challenges. For example, groups interacting around the sphere might face issues caused by non-visible or partially visible display segments [2] or territoriality [10]. Similar issues were discovered and addressed by prior work for tabletop displays [10] and must be addressed in any group learning context. My thesis will capitalize on users' gestural interaction mental models and their collaboration behaviors around spherical displays to support collaborative learning.

3 Completed Work

My completed work was mostly conducted as a part of the NSF-funded Touch Interaction for Data Engagement with Science on Spheres (TIDESS) project, with Dr. Kathryn A. Stofer (PI) and my advisor, Dr. Lisa Anthony (Co-PI).

3.1 Exploring Interaction Design Requirements for Collaborative Learning Around Spherical Displays

Multi-touch spherical displays are a novel learning technology and no prior work had taken a user-centered approach to designing learning interfaces for them. Therefore, my first step was to conduct an exploratory study to lay the groundwork for future research into understanding how users naturally interact and collaborate around spherical displays and identify challenges associated with designing for this novel form factor [13]. With the TIDESS team, I helped conduct an exploratory study in which 27 learners interacted in small groups with a spherical display prototype (Figure 1) to learn about the Earth's ocean using NASA science data visualizations [22]. Our analysis of users' interactions and utterances revealed design challenges to focus on in future prototypes and studies. Our preliminary findings related to users' gestural interactions revealed that children and adults did not always find interacting with the spherical display to be very intuitive due to their unfamiliarity with the form factor. In addition, our preliminary results on group interactions around the sphere helped us show the collaborative potential of spherical displays for informal museum learning settings. However, the mere availability of these displays is not enough to facilitate effective collaborative learning. We also need a deeper understanding of how different interface design features might affect groups' ability to collaborate and learn in museums. These initial findings paved the way for my thesis work in two main areas related to designing effective collaborative learning experiences around spherical displays: (1) understanding how children and adults *naturally interact* with multi-touch spherical displays, to help create a user-defined gesture set that caters to all user age groups, and (2) understanding how groups *naturally*

Figure 1: The sphere prototype used during our first study [13].

collaborate during learning around a sphere to help design more usable and effective learning interfaces.

3.2 Understanding Users' Gestural Interaction Patterns on Spherical vs. Flatscreen displays.

Results from our exploratory study motivated us to investigate how children and adults naturally interact with spherical displays, as opposed to flatscreen displays. Prior research has mapped the gesture design space for flatscreen tabletops [18]. However, it is not clear if the findings from these prior studies can be directly applied to spherical displays. Thus, our next step was to understand the extent to which users conceptualize interacting with spherical displays in a similar or different way as compared to flatscreen tabletops. I led our efforts to conduct a user-defined gestures study, in order to elicit gestures that users naturally attempt for different touchscreen tasks on the sphere and to understand what gestures to support on this novel form factor [15,16]. Wobbrock et al. [18] first used the user-defined gestures method to understand users' gesture preferences for multi-touch tabletops. In our second study, 13 children and 13 adults individually proposed gestures for 17 touchscreen tasks on the sphere (e.g., stop sphere rotation, copy, etc.). In our analysis, we compared (a) physical characteristics (e.g., number of fingers) of user-defined gestures [15] and (b) gestural interaction mental models [16] users had when interacting with the sphere as compared to tabletop displays from prior work [18]. Our findings confirm that the display form factor strongly influences users' mental models of interaction with the sphere. For example, users conceptualized that the spherical display would respond to gestures in a similar way as real-world spherical objects like globes. Based on these results, we proposed implications for gesture design and surface recognition technology for spherical displays. For example, we recommended incorporating a physics engine that considers concepts like friction when developing gesture recognizers for spherical displays. I will use this knowledge in my thesis work to design interactions with science data visualizations for multi-touch spherical displays.

3.3 Understanding Gestures that Facilitate Collaborative Learning on Multi-touch Tabletops

Although not directly related to spherical displays, my research in the early stages of my Ph.D. studies was to understand how to
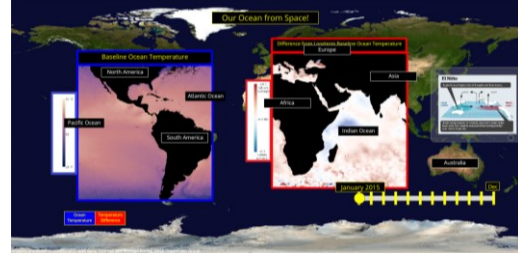

Figure 2: TIDESS tabletop prototype [9,14].

support collaborative learning around multi-touch tabletops using natural touchscreen interactions [9,14]. Prior work on flatscreen tabletops for learning highlighted the key role gestural interactions play in supporting group learning (e.g., [11]). However, prior work has focused on the role of touch interaction in general, rather than looking at what *specific* touch interactions support collaborative learning around tabletops. To understand these specific touch interactions that facilitate collaborative learning from science data visualizations for family groups, I helped the TIDESS team conduct a lab study with 11 family groups. During the study, groups interacted with a TIDESS tabletop prototype (Figure 2). When iteratively designing the prototype, we used two ocean data visualizations each embedded in a "mask viewer," or draggable interactive lens, on top of a base Earth map. Our findings showed that moving and re-sizing the interactive lenses to reveal the underlying temperature patterns guided the groups' thinking process. Our findings also showed the positive role of cooperative gestures [7], which allows multiple users to simultaneously manipulate the interface, in encouraging group members to contribute to science discussion. For my thesis work, I am exploring how to design similar interactive lenses and cooperative interactions to support group learning from science data visualizations around multi-touch spherical displays.

4   Continued Work

Building on my completed work, my plans for my Ph.D. thesis work include studying groups' natural collaboration behaviors and designing and evaluating cooperative gestures to support learning around multi-touch spherical displays.

4.1 Understanding Group Collaboration Around Multi-touch Spherical Displays

The increasing availability of multi-touch spherical displays in museum learning settings [20] affords new forms of co-located collaborative learning opportunities. Thus, we need a deep understanding of how users collaborate around multi-touch spherical displays and the impact of different interface design features on users' ability to collaborate and learn around these displays. In my continued work, I plan to use *F-formations* [5] as a conceptual lens to understand groups' natural collaboration behaviors as they explore global data visualizations around multi-touch spherical displays. F-formations are the spatial patterns formed during co-located group interactions between two or more people (Figure 3) [5]. Prior work has shown that an understanding of F-formations or the way users physically arrange themselves
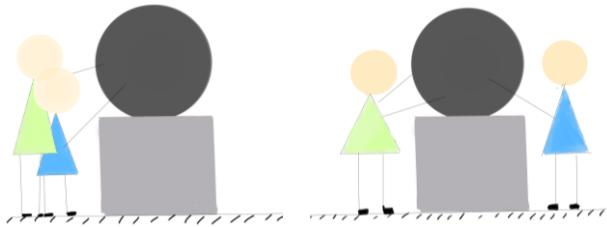
Figure 3: People standing in a side-to-side (left) and vis-à-vis (right) F-formations around a multi-touch spherical display.

Figure 4: *CoralTouch,* **a multi-touch spherical display prototype.**

around a display is important for supporting multi-user collaboration and learning around large interactive displays [4]. This is particularly because F-formations are shown to be linked to group collaboration behaviors that help facilitate learning such as information sharing and group discussion [17]. While prior work has used F-formations as a conceptual lens to understand group collaboration around large *flatscreen* displays [4], these findings cannot be directly applied to *spherical* displays. The spherical form factor can allow users to arrange themselves, share information, and communicate around it in unique ways as compared to flatscreen displays [2]. Thus, it is important to understand how different F-formations and group collaboration behaviors associated with them play out around spherical displays. To answer this, I am currently in the process of qualitatively analyzing a five-day-long museum deployment study, in which visitors (including family groups) were allowed to openly interact and learn from a spherical display prototype about ocean data visualizations. I believe if we could effectively characterize groups' collaborative interactions and associated physical arrangements around spherical displays, we could provide clearer design recommendations to inform the design of future collaborative learning applications for them.

4.2 Designing and Evaluating Cooperative Gestures for Multi-touch Spherical Displays

Our prior work has shown that cooperative (multi-user) gestures facilitated collaborative learning around multi-touch tabletops by encouraging group members to contribute to scientific discussion [14]. To increase the probability that learners engage in similar collaborative interactions around multi-touch spherical displays, in the next step of my thesis work, I will employ user-centered methodologies to design and evaluate a set of cooperative interaction techniques for this platform. Currently, I am in the process of developing *CoralTouch*, a multi-touch spherical display prototype, that will allow family groups to cooperatively interact with data visualizations to learn about the impact of Earth's ocean temperature patterns on coral bleaching episodes. Inspired by our tabletop prototype [9,14], *CoralTouch* will use interactive lenses that can be dragged and re-sized. These lenses will show data visualization patterns in spatially localized areas, thus allowing learners to explore relationships among different science variables such as sea-surface temperature (Figure 4, red outlined oval) and coral bleaching (blue outlined oval) across different geographic locations and time. To iteratively design cooperative gestures for *CoralTouch*, I will draw inspiration from my analysis of groups'

natural collaboration behaviors around the sphere (see 4.1). Additionally, I will conduct in-lab pilots to iron out usability issues and ensure that *CoralTouch* is facilitating collaborative exploration. For example, like our tabletop prototype, in *CoralTouch* cooperative gestures will be used to encourage family groups to jointly manipulate time data to visualize how ocean temperature or coral bleaching episodes change over time and to encourage science discussion. Cooperative gestures might also be used to control the rotation of the sphere during collaborative learning to maintain group coordination and support group discussion. I plan to evaluate the collaborative learning effectiveness of *CoralTouch* during a lab-based study.

5 Open Questions and Issues for Discussion

My thesis goal is to design a multi-touch spherical display application, *CoralTouch*, that helps family groups collaboratively interact with science data visualizations to learn about coral bleaching. There are multiple ways I could benefit from participating in the ISS Doctoral Symposium. I would appreciate any feedback that can help me gain additional perspectives related to group collaboration around non-flatscreen or curved touchscreen displays as well as on designing interactive data visualizations for such displays. Also, I will benefit from a discussion about technical aspects concerning existing SDKs and gestural interaction frameworks that I can build upon when implementing gestures for multi-touch spherical displays.

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