HCI Methodologies for Designing Natural User Interactions that Do Not Interfere with Learning

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ABSTRACT

As emerging touchscreen technologies continue to become more prevalent in learning environments such as science museums and schools, there is a need to understand both principles of interaction design and of learning sciences to create effective educational technology. In this paper, we describe how the HCI approaches we employ in our work can be used to design more effective learning experiences, specifically for interactive touchscreen platforms. As members of an interdisciplinary community, we are exploring the interplay between interaction design research and learning. For example, how can we make sure that users' touch interactions with educational interfaces on these platforms are intuitive, discoverable, and do not interfere with learning outcomes? The "Making the Learning Sciences Count" workshop at CSCL is an ideal setting to share and discuss our evolving understanding at the intersection of interaction design research and learning sciences.

INTRODUCTION

Next-generation classrooms and informal learning settings, like science museums, are increasingly using touchscreen technologies such as tabletops to engage users in touch-interaction based learning experiences [3]. With this transition towards more interaction-based learning comes new research opportunities for designing interactions that are natural and easy to use for learners. If interactions enabled by educational interfaces are not intuitive, learners' attention may shift towards understanding the interface rather than engaging with the educational content [1]. Thus, there is a need to understand both principles of interaction design and learning sciences theory to design effective educational technology that affords deeper engagement and learning. In this paper, we discuss approaches from human-computer interaction (HCI) we have adopted to design effective educational technology informed by learning science theory. First, in the TIDRC project, we discuss how interaction design guidelines based on children's cognitive and physical abilities are being overlooked in commercial touchscreen apps [9]. Second, in the TIDESS project, we discuss how we employed user-centered design approaches for developing learning experiences that consider users'

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natural interaction behaviors across different form factors such as spherical and flatscreen tabletop displays [10–12]. We argue that overlooking interaction design principles when designing educational technology can lead to poorer learning because of usability difficulties experienced by learners. Our work provides insights into how understanding the ways that users naturally interact with touchscreen gesture-based technology can improve interaction in learning settings.

HUMAN-COMPUTER INTERACTION METHODOLOGY IN THE "TIDRC" PROJECT

In the TIDRC project, we, along with our collaborators, are trying to understand how well research-based design guidelines for children's touchscreen interfaces are applied in practice by app developers who build the educational apps children use every day [9]. Our learning goal is to ensure that children's educational touchscreen apps are designed based on their cognitive, physical, and socio-emotional needs, because developmental appropriateness of an educational system has a significant impact on children's learning [15]. We analyzed 50 children's iOS apps based on a framework of Touchscreen Interaction Design Recommendations for Children (TIDRC, "tide-rock"), consisting of 57 recommendations. The TIDRC framework encompassed design guidelines for interface components such as visual design, audio, and interactive features of touchscreen apps. Our analysis showed that designers have a good awareness of children's motor abilities, but children's cognitive needs are not well-supported within touchscreen mobile apps. For example, most apps did not provide enough *scaffolding* while children interacted with them. For more information on the study design and analysis, see [9]. Following this methodology helped us closely analyze the design practices of app designers and demonstrated how involving stakeholders other than just the users of an educational technology can also help shape learners' interaction experiences. By grounding our app evaluation framework in the interaction design literature, we were able to use prior findings based on psychology, cognitive sciences, and learning sciences theory as an analytical lens to pinpoint opportunities for future improvements in the design of touchscreen apps. Using this knowledge, we aim to make app developers aware of critical areas of improvement within the design of children's apps with respect to their developmental needs.

HUMAN-COMPUTER INTERACTION METHODOLOGIES IN THE "TIDESS" PROJECT

Large touchscreen interfaces like multi-touch tabletops and spherical displays offer educational opportunities for both children and adults in public spaces [3,16]. Through an NSF-funded project called TIDESS ("Touch Interaction for Data Engagement with Science on Spheres") [17], we, along with several collaborators, are trying to understand how children and adults interact with large touchscreen interfaces, to help us design natural interactions for learning on these platforms. We have used three HCI empirical study methodologies in the TIDESS project to consider interaction design principles for children and adults. It is vital to study both children and adults because children's developing motor and cognitive skills are shown to impact their touchscreen interactions [2,9]. Next, we discuss three user-centered design approaches as examples of ways to gather and analyze information about learners' natural interactions with educational touchscreen interfaces that should help us design more usable and effective learning experiences for these platforms.

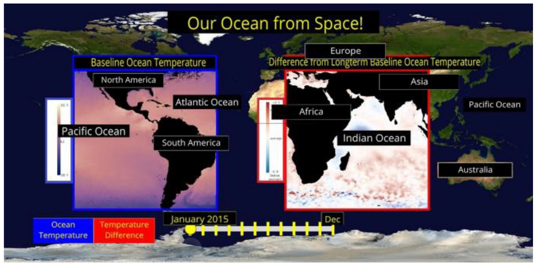

Figure 1: TIDESS interactive data visualization prototype on the flatscreen tabletop platform.

Figure 2: TIDESS prototype ported to the interactive spherical display platform.

(a) A Lab-based Study to Explore the Link between Touchscreen Gestures and Learning. Our first lab study aimed to investigate the role of touchscreen gestures in supporting collaborative learning around tabletop displays [11]. To investigate the link between gestures and learning, we developed design goals that incorporated both HCI and learning sciences (e.g., “support learning about Earth’s ocean through collaborative interactions”). Through an iterative design process with an informal observational study and in-lab pilots, we built a tabletop prototype (Figure 1) supporting learning about data visualizations of Earth’s ocean system. Key interface elements of our prototype included two draggable and re-sizable “maskviewer” elements, containing map views showing ocean temperature data, along with a two-handed time slider (yellow bar in Figure 1) to allow learners to observe temperature changes over time. Based on a lab study with 11 family groups, analysis of learners’ utterances and touchscreen gestures revealed that learner groups used our maskviewer elements to bring key aspects of the science content into focus, and used cooperative gestures with two-handed elements like the time slider to create a shared group memory. For more information on the prototype, study design, and analysis, see [7,11].

The methodology we followed used an iterative design process from HCI to inform the design of our tabletop prototype. Our learning sciences goals included enabling learners to *explore* the visualizations across the whole space and draw *conclusions*. Specific HCI goals were linked to our learning sciences goals, e.g., to design the affordances of our prototype to allow learners to explore the data visualizations through *discoverable* and *quick interactions*. By following an iterative design process, which involved prototyping and continuously evaluating improvements, we ensured that our prototype was fulfilling both learning sciences and HCI goals. In our analysis, we logged learners’ touch interactions and later combined them with their utterances during our qualitative analysis to help us interpret our findings. Following this analysis approach helped us to see the role of touchscreen gestures in supporting science learning.

(b) A Design Probe Study to Understand Interactions with Interactive Spherical Displays. Novel learning technologies like interactive spherical displays are being used for educational purposes in public spaces [4]. The goal of our exploratory study was to investigate learning affordances and the interaction design space for spherical displays. We ran an exploratory study using a version of our tabletop prototype that was ported to a spherical display (Figure 2) as a design probe to see how 27 children and adults in six small groups (children only or adults only) interacted with a touch-driven spherical display in a public setting. Our qualitative analysis was based on videos and touch logs. We saw that, unlike adults, children explored new interaction possibilities offered by the spherical displays. Also, echoing other prior work on children’s collaborative learning behaviors, in our study children interacted more independently than adults, while sometimes exhibiting negative group behaviors like fighting for position [8,10,14]. For more information on the study design and analysis, see [10]. Observing how users naturally interacted around spherical displays helped us define the design space for spherical displays and point to future research opportunities. We had the same learning science goal as in (a), to enable learners to *explore* the visualizations and draw *conclusions*, but this time to also understand the learning affordances of spherical displays. Specific HCI goals included identifying users’ natural interaction patterns around the sphere. Rather than giving pre-defined tasks to our participants to complete during the study,

Table 1: Mapping HCI methodologies with learning sciences research questions based on our studies [7,9–12].

HCI methodologies	*Learning science research questions/outcomes*
Empirical analysis of touchscreen apps	This HCI technique helped us evaluate real-word interface design practices of children's educational touchscreen apps with respect to research-based design recommendation by evaluating iOS apps against research-based interaction design guidelines.
The iterative user-centered design process, (in-lab and real-world settings such as museums)	This HCI technique helped us design a tabletop prototype to investigate the role of touchscreen gestures in supporting collaborative learning around tabletop displays by analyzing what touch gestures were learners making while learning.
Exploratory design probe study (real-world setting such as a public library)	This HCI technique helped us explore the interaction design space and learning affordances of a novel learning technology like interactive spherical displays by analyzing learners' utterances, interactions, and group dynamics.
Gesture elicitation study (in-lab controlled experiment)	This HCI technique helped us understand users' gesture preferences for spherical displays by analyzing the gestures users proposed for touchscreen tasks and their though process while they proposed the gesture.

we used the prototype as a design probe and asked our participants to interact with it as they would if they encountered it in a real-world setting, e.g., museums. In this HCI method, the prototype itself acted as a design probe to further user discussion [5] and helped us understand learners' context-specific interactions with a novel learning technology like spherical displays. In addition to analyzing users' utterances and touch logs, we also analyzed group dynamics around the sphere, since these have been shown to impact learning around large touchscreen interfaces [8].

(c) Comparing Touch Input Patterns for Flatscreen Tabletops and Spherical Displays. In order to continue to work toward the TIDESS project's learning sciences goal of enabling learners to *explore* scientific data visualizations and draw *conclusions* on touchscreen platforms, we developed a new HCI goal to understand users' gesture preferences and whether the form factor of the display (e.g., spherical vs flatscreen displays) might influence users' gesture preferences. We conducted a gesture elicitation study [13], intended to elicit gestures that children and adults naturally try for different touchscreen tasks on the sphere. We asked 13 children and 13 adults to propose gestures for 17 interaction tasks (e.g., stop sphere rotation, copy, undo) on the spherical display. For our analysis, we classified the elicited gestures based on their physical structure (e.g., number of fingers) and compared the gestures our participants proposed to gestures elicited for tabletop displays in prior work [13]. We saw that both children and adults were more likely to perform multi-finger or whole-handed gestures on the sphere as opposed to tabletop displays. We also saw that children tended to use more gestures involving dynamic hand poses that require ongoing recognition than adults. For more information on the study design and analysis, see [12].

Using the HCI gesture elicitation methodology helped us gain a deeper insight into the thought process behind participants' interactions. For example, we observed that users seemed to conceptualize the spherical display more as a vertical wall rather than a flatscreen display [12]. This access to users' thinking helped us understand what gestures to support on this new spherical platform based on *users'* preferences, instead of just using *designer*-defined gestures, which can be conceptually complex for users [6]. If a new platform like the spherical display fails to respond to users' exploratory gestures that they try in a new setting, it may lead to frustration and low user engagement. In learning applications, consequently, learners might then prioritize focusing on learning the interface rather than the educational content. On the TIDESS project, we will use our findings to design gestural interactions with science data visualizations on spherical displays.

CONCLUSION

Building effective educational technology that is responsive and adapts to users' natural interaction behaviors requires elements from both learning sciences and interaction design (HCI) research. We discussed several HCI interaction design methods (e.g., user-centered design, design probe) and data / analysis techniques (e.g., touch logs, think-aloud) that can inform the design of interfaces that allow learners to focus on learning, rather than on interacting. As a summary, Table 1 provides a mapping between HCI methods and learning sciences research questions based on our studies with children and adults. This knowledge will support further progress in understanding how to design touchscreen interactions (e.g., gestures) that do not interfere with learning.

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