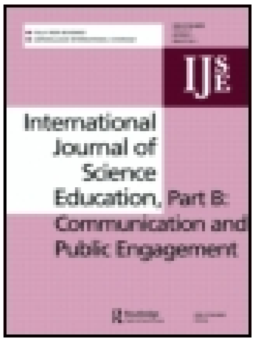

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Technology-mediated engagement with nature: sensory and social engagement with the outdoors supported through an e-Trailguide

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ABSTRACT

This study describes the implementation of a self-guiding mobile learning tool designed to support youths' engagement with the natural world as they explored the flora and fauna along one nature trail at an environmental center. Using qualitative video-based data collection and analysis techniques, we conducted two design-based research study iterations that documented interactions between technology, learners, and nature. Children ($N = 83$) between the ages of 8 and 11 used an iPad-based e-Trailguide designed for a nature trail at a summer camp. Analyses focused on three types of engagement between the learners and the natural world that were facilitated by the e-Trailguide, which we refer to as technology-mediated engagement with nature: (a) observation, (b) pointing, and (c) tactile investigation. Alongside the development of this framework for technology–child–nature interactions, our findings also include the emergence of a learning pattern with regard to technology-mediated engagement with nature: a specific order to the way that children engaged with nature with observations first, pointing second, and tactile investigations third. We also found increased engagement with nature among the children during the second iteration of the study when they used an interactive data collection tool embedded within the e-Trailguide. Design considerations for the future implementation of e-Trailguides in outdoor settings include the incorporation of textual prompts and questions to facilitate observation, development of joint observational activities to encourage collaborative learning, and articulated directions to promote tactile investigations of natural objects.

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Mobile learning; outdoor learning; engagement; environmental education; informal science learning; summer camp

Mobile technologies are being increasingly integrated into outdoor science learning settings to mediate learning experiences about the natural world (Jones, Scanlon, & Clough, 2013; Rogers et al., 2004; Zimmerman & Land, 2014; Zimmerman et al., 2015). Research has demonstrated how mobile devices facilitate learning during environmental education programs during school field trips in relation to knowledge change (Chang, Chen, & Hsu, 2011; Chen, Kao, Yu, & Sheu, 2004), participation in the practices of science (Rogers et al., 2004; Rogers, Connelly, Hazlewood, & Tedesco, 2009), and identity towards science (Dunleavy, Dede, & Mitchell, 2008; Jones et al., 2013). While the focus on school-based studies has provided a foundation of design principles for school-based technology-enhanced learning, less analytic attention has been paid to how mobile devices facilitate out-of-school learners' engagements and interactions with the scientific, natural world. Our work addresses this gap in understanding of how to develop out-of-school time technology-enhanced

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learning environments that focus on science learning outdoors in summer camps and other informally organized programs.

Theoretical framing

The sociocultural view on science learning guides our research and development project. Sociocultural learning processes include more than just the cognitive learning process; it considers the people, cultural tools, and the setting where an activity is situated to be important shapers of a learning experience (Brown, Collins, & Duguid, 1989). Sociocultural science learning includes a focus on the practices of science, such as honing observation skills (Eberbach & Crowley, 2009), collaborating about science to refine understandings (Roschelle, 1992), and making thinking visible through conversation with others (Collins, Brown, & Holum, 1991). As such, we attend to content knowledge (on native animals and plants) and the social interactions within our research project, as well as the individual learners.

Place-based learning in the outdoors

Place-based learning theory, which considers the importance of connecting learners with their community by anchoring pedagogy within the context of the local natural and social ecosystems (Ardoin, 2006; Gruenewald & Smith, 2014), led the design of our e-Trailguide. We build on the assumption that learning about nature must occur in the people's local places and spaces (Ballantyne & Packer, 2009; Brody, 2005) as these experiences can later serve as the foundation for future understandings of distant or abstract phenomena (Smith, 2002). Emphasizing the importance of the local space to guide learning experiences, Tal, Lavie Alon, and Morag (2014) identified 'using the environment' as one of four distinct, exemplary pedagogical practices observed amongst 62 field trip sites. In their analysis and evaluation of field trips to nature and archaeological sites for students in grades 4–8, Tal and colleagues reflected that, 'it was surprising how many of the guides we followed almost ignored what could be seen, touched and felt in the field' (p. 9). To this end, we created a digital fieldguide that would facilitate a place-based learning experience aimed at promoting engagement with the local flora and fauna during nature walks.

Our work that investigates how to support engagement in the outdoors is motivated by critiques such as Ruchter and colleagues' (2010) lamentation that 'the alienation from nature' is a fundamental challenge for environmental educators who aim to implement computer-mediated learning opportunities in outdoor spaces. Despite this assertion, Jones et al. (2013) argue that one advantage of using digital devices in outdoors is the ability for learners to access resourceful information *in situ* to identify what they are seeing as they see it, such as local and migrating birds. Given the importance of creating place-specific resources, we included only locally collected photos, videos, and audio recordings in the e-Trailguide. Additionally, the information included in the e-Trailguide corresponded to the specific physical locations along the nature trail, providing a more relevant learning experience for visitors.

Engagement as learning in informal learning spaces

Researchers studying learning outside of school often look at engagement in informal science education spaces as a proxy for science learning. Building from definitions of engagement from Barton, Drake, Perez, St. Louis, & George (2004), engagement includes people's personal involvement in, orientation towards, and socio-historic participation of a learning event. Here, we limit the term engagement to be people's involvement, orientation, and participation towards nature and science as mediated by hand-held technologies on a nature trail.

Heath and vom Lehn (2008) argue that accounts of how users engage with technology in informal learning spaces are sparse in the educational literature—despite it being an important goal for designers of out-of-school time programs and museum exhibits. In their own work, Heath and vom Lehn (2008) studied engagement and defined it as the extent to which museum exhibits promote ‘interactivity’ amongst visitors. They described interactivity as both tactile investigations and social communication with others in the exhibit area. As such, the authors argue that ‘interactivity’ is critical to engagement and learning in museums.

Characteristics of science learning and engagement with mobile technologies

In the out-of-school technology-enabled learning literature, research has found that ideal technology-enabled learning processes include a ‘heads-up’ behavior where users are engaged not just with a screen, but also with making observations of their surroundings. Visitors using technologies in informal spaces have a tendency to be ‘lured by the screen’ (Filippini-Fantoni & Bowen, 2008). This has become known as the ‘heads-down phenomenon’ (Hsi, 2002; Lyons, 2009) where visitors’ attention is not on their peers or the site but on the mobile computer or exhibit screen. Consequently, Pea and Sharples (2014) suggest that mobile learning platforms be designed so as to enable users’ engagement in the tasks to be accomplished, rather than on the devices themselves. Similarly, Sung and colleagues (2010) argue that a holistic ‘visitor–computer–context’ dynamic can be achieved in the design of computer-based guidebooks for informal spaces, where visitors use the computer to channel attention to and interact with the physical environment of a museum. In their Ambient Wood project with 20 school children on a field trip, Rogers and Price (2008) documented this heads-up interaction at play. They found that the students’ observations in a wooded ecosystem were aided by the information provided on the mobile devices.

A second form of engagement, pointing, we posit is a social sign of interaction with nature. Pointing is a deictic gesture—a physical movement that combines with speech in order to orient others towards an object of interest within the immediate setting (Goldin-Meadow & Alibali, 2013; Roth, 2001). In education, pointing can play an important role in collaborative learning activities, while it also serves as a mode for externalizing one’s thinking and understanding of a concept (Roth, 2001). For example, in a museum with computer-based exhibits, Meisner et al. (2007) observed from 20 hours of video of museum visitors (ranging from school groups to families to individuals) interacting together that gestures were important modes of conveying meaning in groups. In our framework, we view pointing as a means of orienting others towards a natural object of interest on a nature trail.

A third type of engagement involves tactile investigations of natural objects, which we consider to be important for connecting people with nature and science. In informal settings, high-level sensory interactivity has been sought through the implementation of ‘hands-on’ exhibits (Gutwill & Allen, 2002), which require the use of learners’ mind and body (Allen, 2004). Interactions with exhibits are thought to promote understanding and recall of exhibits’ science content (Allen, 2004, p. S24). While museums design exhibits that promote these direct sensory experiences for visitors, on nature trails, hands-on interactivity is more challenging to document and to encourage. For instance, while sensory interactions do occur, there are also plants that learners are discouraged from touching (e.g. poison ivy) and animals that visitors cannot reach or that move too quickly to touch. Nonetheless, encouraging sensory engagement with the outdoors is an important piece of environmental education pedagogy (Ballantyne & Packer, 2009). In their interviews with 39 teachers who led environmental education programs for students in the context of the outdoors, Ballantyne and Packer recorded the teachers as believing that having ‘hands-on opportunities’ had the greatest impact on student learning. When mobile devices are integrated as learning tools into outdoor spaces, tactile learning has been shown to result (e.g. Zimmerman et al., 2015). In their work at an arboretum with 10 family groups, Zimmerman et al. (2015) observed the families as they used mobile devices to facilitate closer inspections of the trees onsite. The scientific images on the mobile devices influenced the parents and children to physically touch parts of the trees, like the bark, to contextualize their understandings and observations.

From this three-prong categorization of engagement with nature and science presented above (i.e. heads-up observations, pointing, and tactile investigations), we have created a conceptual framework we describe as 'technology-mediated engagement with nature' to guide our research and design. We use this framework to make design choices that foster learners' engagement with the natural world, as well as to analyze the video data. Through our study, we illustrate that engagement with nature can be fostered when technology is introduced into the learning experience. In our study, we answer three research questions:

- What types of engagement between learners and the natural world are mediated through the use of an e-Trailguide tool?
- What design features of an e-Trailguide prompt the children's engagement with nature (e.g. what is the role of textual prompts, questions, and joint activities embedded within the e-Trailguide)?
- In what ways can learners' engagement patterns be influenced when data capture tools (i.e. a sketchpad widget) are included in the e-Trailguide?

Study design and methodology

This study leveraged a qualitative, design-based research (DBR) method to investigate learners' engagement with nature. We selected DBR (Collins, Joseph, & Bielaczyc, 2004; Land & Zimmerman, 2015; Sandoval & Bell, 2004) as a methodology because it is an inquiry tool to inform design, theory, and practice concurrently through iterative implementations of an educational intervention. In this study, we conducted two iterations of research and development on the learning processes that occurred during interactions between children and nature with mobile technologies. A qualitative form of DBR was chosen to develop and refine informal learning theory and our analytical framework related to technology-enhanced engagement.

Two DBR iterations were conducted with the e-Trailguide (see Table 1) in order to understand how the e-Trailguide facilitated the children's interactions with the biota along the nature trail during summer camp. The two iterations were feedback cycles (Bannan-Ritland, 2003) that helped us to 'sharpen aims [and] deepen contextual insights' (McKenney, Nieveen, & Akker, 2006, pp. 77–78), especially since we were situating our study within the complex setting of a nature trail with varying organisms. As such, we used a design-enact-analyze-revise (Puntambekar & Sandoval, 2009) study design.

Setting

The environmental center where this study took place is Shaver's Creek Environmental Center (SCEC), which is located in the mid-Atlantic region of the United States. SCEC receives thousands of visitors annually and is associated with The Pennsylvania State University. The property attracts visitors in part because it is host to over 20 birds of prey that are visible to the public daily. Many

Table 1. Types of technology-mediated engagement with nature.

Types of technology-mediated engagement with nature	General description of engagement patterns
Observation	'*Heads-up' movements or observations* indicated that learners were responding to the content in the e-Trailguide by looking out into the landscape or at a natural object closely
Pointing	*Pointing* indicated that learners were actively connecting a concept introduced in the e-Trailguide to the surrounding area or natural object located along the nature trail
Tactile investigation	*Tactile investigation* of a natural object along the trail indicated that learners were using a hands-on approach to investigate a biological specimen introduced in the e-Trailguide

kilometers of hiking trails wind through SCEC's forestland; one trail—the Boardwalk Trail—was the focal point of our study. The Boardwalk Trail (described in more detail in the next section) takes visitors through an area of mixed hardwood trees, a marsh habitat, and ends in a mossy, conifer[1] forest. This trail has an ADA-approved (Americans with Disabilities Act) surface, which is smooth, level, and stroller-friendly and wheelchair-accessible.

The design of the e-Trailguide

In alignment with sociocultural learning theories and by using the conceptual framework of technology-mediated engagement with nature, we designed the e-Trailguide to facilitate learners' engagement with the natural world that included a coordination of the learners' senses, the science content of the e-Trailguide, and the learners' surroundings, including their peers. Given that our study occurred within a 7000-acre university-owned hardwood forest, Internet and cellular phone reception were limited. Consequently, a technology tool that did not require any access to the Internet was required, such as an electronic book, or an Apple Inc.-based iBook. A benefit of iBooks is that it increases scalability of the design findings to other nature centers, given that only minor computer programming skills are needed to design and implement an iBook.

The e-Trailguide designed for SCEC is an interactive iBook, which serves as a self-guiding tool for visitors to use while hiking along the 0.5 km Boardwalk Trail on SCEC's property. The lead author developed the iBook with embedded prompts, questions, and activities throughout the e-Trailguide as strategies to foster children's engagement with nature. The iBook software provided for a means to include interactive features, called widgets. Widgets for drawing, entering data, and recording fieldnotes were included. Not only do iBook's widgets provide innovative affordances that separate the e-Trailguide from a standard paper-based guidebook, but they are also important for encouraging the individual learners' science interests by allowing them to observe and draw a natural object of interest, like a tree, via a sketchpad widget or to collect fieldnotes via a notebook widget.

Within the e-Trailguide, seven Discovery Spots are laid out as book chapters, which correspond to seven sites of interest along the Boardwalk Trail. A map showing the designated Discovery Spots at the end of each 'chapter' aims to keep the users geographically oriented. At each Discovery Spot, seasonal information is presented through videos, photos, and audio files. All iBook media were collected locally by staff members and affiliates of SCEC. The e-Trailguide also includes six 'On the Move' activities, which are challenges designed for explorations between each Discovery Spot. For example, one On the Move activity features a scavenger hunt about seasonal plants and animals.

Participants

The research participants were children ($N = 83$) who were attending SCEC's 2013 summer day camp, a nature program that included over 24 hours of outdoor-based, informal learning in one week, and that consented to be in our study. The children, who were between the ages of 8 and 11, included a relatively even proportion of males ($n = 45$) to females ($n = 38$). In the first iteration, 42 children participated. In the second iteration, 41 children participated. During each session of data collection, children interacted with the e-Trailguide in pairs sharing one iPad. The pairs in all study iterations explored the same nature trail for the same amount of time (one hour).

Data collection

Following the practices of learning sciences (Derry et al., 2010) and museum-based (Allen, 2002) video research, qualitative data collection practices were implemented within our DBR study. The primary data were video-records that captured children's dialogue and gestures related to the technology, nature, and peers. The lead author video-recorded each group's nature trail experience with the e-Trailguides in its entirety. A total of 15 one-hour sessions (8 sessions in iteration 1; 7 sessions in iteration 2) comprise the total video data. These data were transcribed before analysis.

Data analysis

The video-records were analyzed with line-by-line coding as well as thematic analysis related to the children's engagement with the natural world. Coding was conducted using the three concepts of technology-mediated engagement with nature as defined and refined based on iterative passes through the data:

(1) heads-up observations (Hsi, 2002; Lyons, 2009),
(2) pointing (Goldin-Meadow & Alibali, 2013; Roth, 2001) to plants and animals along the trail, and
(3) tactile, or hands-on, investigations of natural objects along the trail (Zimmerman et al., 2015).

Our coding scheme is summarized in Table 1, which includes the types of engagement that we coded for, as well as a general description of each type of technology-mediated engagement with nature.

During the coding process, the codes in Table 1 were only applied to learners' actions that were in response to information in the e-Trailguide. For instance, there were numerous instances of looking around and pointing at objects while the children walked on the nature trail; however, we only coded for the technology-mediated engagement with nature moments when they looked at or pointed at something in response to a prompt from the e-Trailguide content. Interrater reliability was 0.9 agreement using a sample of 10% of the video data that were independently coded by two individuals. Any disagreements on this portion of the video data were discussed and agreed upon by the researchers.

Focal analysis on Discovery Spot #3

Thematically, we examined how certain features of the e-Trailguide affected the amount of engagement between iteration 1 and iteration 2. In implementing a DBR study, we carefully examined the videos from the first iteration in order to make the necessary revisions to the e-Trailguide for the second iteration. In making these changes, we wanted to look at the differences in engagement levels, if any, between iteration 1 and iteration 2. There was one widget—the sketchpad for drawing—that was well-received and highly used amongst the children in iteration 1. For this reason, we added an additional sketchpad widget to the second iteration of the e-Trailguide. Since the addition of a sketchpad widget at Discovery Spot #3 in iteration 2 was the most extreme change made to the e-Trailguide between iterations, we created a case study to investigate how learners' interactions with nature may have shifted at Discovery Spot #3 between iterations 1 and 2. Therefore, additional coding occurred that was only focused on instances of nature and science engagement at Discovery Spot #3.

Findings

Our findings elucidate the science learning processes related to engagement that the e-Trailguide facilitated between the learners and the natural world. To illustrate our findings, short transcriptions from the data set are included in this article. **Bold font** represents the application of our coding scheme to the data. Learners' gestures are represented on the transcripts through double parentheses [(())]. *Italicized font* indicates that a learner was reading from the text found in the e-Trailguide.

Technology-mediated engagement with nature

There were several features of the e-Trailguide that enabled the children's engagement with the natural world as we observed instances of interaction that included: (a) heads-up observations, (b) pointing to a plant or animal nearby, and (c) tactile investigations of a natural object along the trail. In the following sections, each of these types of engagement will be contextualized with an example gleaned from our data corpus.

Engagement with nature through observation

This first type of engagement was documented when children reacted to content in the e-Trailguide by looking up from the screen to outwardly observe features of the landscape. It was the most common type of engagement across our study. Our video analysis revealed that heads-up observations occurred nearly one time per minute, per pair (672 instances per 15 hours). While several design features of the e-Trailguide contributed to these heads-up observations, the majority of these moments resulted from specific textual prompts or questions that focused the children's observations on specific features of the landscape at Discovery Spots along the trail.

Each Discovery Spot featured specific content based on the uniqueness of that area of the trail. For instance, Discovery Spot #2 focused on content related to wild grapes in the area and the grapevines that can be seen from that spot on the trail. In the e-Trailguide, prompts and questions such as, '*During the summer, it is difficult to see the grapevines because they are covered with leaves. Can you find any as you look around you?*' were simple, yet effective ways of encouraging pairs to immediately look up after reading the text to point out to their partner the grapevines they found. In one example, this prompt from Discovery Spot #2 is played out in the following vignette between two partners, Amber and Colin:

Amber: ((reading from e-Trailguide)) Did you know that wild grapes are native to Pennsylvania? Cool! Grapes grow on vines that twist all around a woody forest- the kind of forest you are in now. ((Amber and Colin both **look up** into forest in front of them)) Okay! Cool! ((looks down at device to continue reading)) During the summer, it is difficult to see the grapevines in our forest because they are covered with leaves. Can you find any as you look around you?
Colin: ((**looking around**)) Ohhhh.
Amber: ((**looks up** from device)) Do you see any?
Colin: ((takes a few steps to the right)) Is that … ? That! ((**points**))
Amber: ((**gaze follows Colin's pointing**)) Oh yeah! There's one!

In this example, Amber reads out loud from the e-Trailguide about local grapevines to herself and to her partner, Colin. At this Discovery Spot, Amber reads the text ('*Grapes grow on vines that twist all around a woody forest- the kind of forest you are in now*'), which sparks the first heads-up movement for both Amber and Colin. Amber responds by saying, 'Okay! Cool!' then looks down at the device to continue reading the content and reads the first question out loud: *During the summer, it is difficult to see the grapevines in our forest because they are covered with leaves. Can you find any as you look around you?* This question resulted in a more heightened level of engagement that took the children from observing their surroundings to actively pointing at a specific natural object: Amber asked Colin if he could see any grapevines and he pointed one out to her. This example provides an exemplary learning moment in which both children were provoked by the e-Trailguide's content to observe their surroundings. Carefully worded textual prompts and questions that were specific to places along the nature trail, as demonstrated in the above example, encouraged heads-up observations for the children, allowing them to connect what they were reading to their real-world observations.

Engagement with nature through pointing

As was seen in the previous example with Amber and Colin, pointing to plants along the trail was an active interaction that signaled a different type of engagement. Pointing indicated that the children were coordinating the textual prompts from the e-Trailguide to the outdoor trail as they actively observed and described to their partner where something was located, or to gesture about the shape of a tree through arm movements. Pointing occurred one time per every two minutes, per pair (377 instances per 15 hours). We noted that pointing was a common form of engagement during On the Move activities as these were designed to encourage collaborative group explorations of certain parts of the trail.

The first On the Move activity, for example, acted as a follow-up to Discovery Spot #1, which provides content about a tree that arches over the trail due to weak internal structure coupled with inclement weather. In this first On the Move activity, the children were challenged to count all the 'arching trees' they could find as they walked the short distance to Discovery Spot #2. This simple observational activity resulted in pointing by the partner pairs as a method for confirming their finds with one another, as was seen with Seth and Nathan. Nathan was holding the iPad and after reading the prompt for On the Move activity #1 ('*As you walk to the next Discovery Spot, look around you. How many "arching" trees can you find?*'), he and Seth walk down the trail and begin pointing and counting out loud the number of arching trees they see around them:

Seth: Three ((**pointing** and walking))
Nathan: Three ((holding iPad and **looking around**))
Seth: Four ((leans forward by Nathan to **point out** the fourth arching tree he found))
((Nathan and Seth turn to the right and continue **looking into the forest**))
Seth: ((looks at Nathan)) Wait, did we count this one? ((**points up** to largest arching tree bending over the trail))
((Nathan shakes his head no))
((Nathan and Seth continue walking down the trail while **looking around**))

Here, we observed that the activity presented in this On the Move activity sustained heads-up observations by both Seth and Nathan. Coupled with this was Seth's frequent and rapid pointing. As Seth and Nathan walked down the path in search of arching trees, they both counted out loud and Seth pointed to the trees they observed. When Seth counted the fourth arching tree, he checked to make sure that Nathan also saw the same tree by leaning in close to Nathan and pointing up into the forest. Before moving down the trail, Seth asked 'Wait, did we count this one?' and pointed up to the large arching tree bending over the trail to which Nathan shook his head signaling 'no'. This On the Move activity, among others, was intentionally designed to encourage deep observations of the surrounding landscape. This example with Seth and Nathan demonstrates that such joint activities provide not only opportunities for engagement with nature through pointing, but also collaborative learning moments between partners.

Engagement with nature through tactile investigation

The third type of engagement was seen the least often across the children in our study, about 1 instance per 20 minutes, per pair (48 instances per 15 hours). During the second On the Move activity, children were challenged to match different colored blocks in the e-Trailguide to natural objects they found along the trail as they walked to Discovery Spot #3. This activity resulted in a very tactile exploration of the trail where children either picked up objects to place directly onto the iPad or held the iPad right up against an object to compare colors.

During this second On the Move activity, Bradley and Thomas are walking down the trail looking for colors that matched the colored blocks shown in the e-Trailguide:

Thomas: Red! ((**points** to a spot along the trail))
((Bradley walks over to the spot with the iPad; he leans down to put **iPad against the plant** to see if it is the same shade of red as shown in the e-Trailguide)).
Thomas: Not dark enough.
Bradley: Eh. No.
Thomas: No, it's not dark enough.
((Bradley pulls iPad away and continues walking down the trail))

In this episode, both Thomas and Bradley were walking down the trail while continuously looking at the colored blocks in the e-Trailguide and the surrounding landscape to find natural objects that matched the colors. At one point along the trail, Thomas saw an object and said, 'Red!' while pointing to where he was looking. To make a closer comparison, Bradley, who was holding the iPad, walked closer to the object along the trail and leaned down to hold the iPad against the plant. Thomas then concluded that the object was 'not dark enough' to be an acceptable match. By physically placing the iPad against the natural object they had observed, Bradley and Thomas engaged in a deeper exploration of their surroundings. In this example, engagement with nature through tactile investigation was preceded by both observation and pointing. This sequence of events (observing–pointing–touching) was a common pattern found across the groups; it is discussed in the next section.

A leveled order to youths' technology-mediated engagement with nature

Through analyzing the video-records and tabulating the instances of the three types of engagement occurring amongst the children, a hierarchy in the level of engagement with nature emerged. Heads-up observations occurred most frequently in 672 instances (61%), while pointing occurred in 377 instances (34%) and tactile investigations occurred the least often in 48 instances (4%). Given this pattern, we found an order to the different levels of technology-mediated engagement with nature: observations were youths' first level of engagement, pointing was the second level of engagement, and finally, youth engaged in tactile investigations as a third level of engagement. Although we use the terms 'first,' 'second,' and 'third' to define the different levels of engagement, we are not implying a hierarchy. Instead, this is the order of learners' engagement and is tied to the ease with which one can design (or not design) for different kinds of engagement with nature. For example, the textual prompts and questions featured at Discovery Spots were relatively simple and straightforward methods for encouraging children to coordinate the mobile media with the outdoor setting and observe their surroundings. Pointing was also a common occurrence in our study and occurred as children talked to their peers and clarified their observations with each other during On the Move activities where they were challenged to achieve a goal as a collaborative group. The third level of engagement with nature through tactile investigations of a natural object was a challenge to design for in our study and, as a result, occurred only 4% of the time during the children's experience on the nature trail.

In relation to these levels of engagement, a pattern emerged in our study whereby the three different types of engagement with nature commonly built off of one another in a step-wise fashion. The first stage of this sequence occurred when a child read a textual prompt or activity directions from the e-Trailguide. If the prompts were effective in facilitating engagement with nature, the child reading the prompt out loud and his or her partner listening to the prompt first engaged with their surroundings by looking up and observing the feature of the landscape being described in the e-Trailguide. If the children remained engaged, they next pointed to the natural object, confirming their observations with their partner. The last stage of this sequence was also the least common in our study. In these moments, the children first explored the landscape by observing their surroundings, then pointed out something of interest, which then led to a deeper exploration of the natural object by either touching it with their hands or by holding the iPad up to that object to compare images displayed on the device.

Changes in engagement between iterations

Design of e-Trailguide in iteration 2

After reviewing the video data from iteration 1, we found that children in this first iteration of data collection spent a large amount of their time on the hiking trail looking at the screen in order to read the information presented. Because we aimed for the e-Trailguide to foster engagement with the natural world, rather than just reading, revising the design of the e-Trailguide was an important

Table 2. Mobile material design and revisions, showing the differences in the two iterations based on our study findings.

Iteration	Subjects	Design iterations of e-Trailguide described
Iteration 1: 8 sessions	42 children, aged 8–11	Initial text design included about 56 words per chapter, 1 video, 81 graphics, and 2 interactive widgets (i.e. 1 sketchpad widget, 1 checklist widget)
Iteration 2: 7 sessions	41 children, aged 8–11	Redesigned text included about 38 words per chapter, 2 videos, 97 graphics, and 4 interactive widgets (i.e. 2 sketchpad widgets, 1 checklist widget, 1 notebook widget), based on the analysis of iteration 1

Table 3. Iteration 1 vs. iteration 2 at Discovery Spot #3: Changes in engagement.

Iteration period	Observation	Pointing	Tactile investigation
Iteration 1	62 instances	16 instances	5 instance
Iteration 2	149 instances	37 instances	7 instances

step in our DBR project. As such, the revised version of the e-Trailguide in iteration 2 (see Table 2) included a 32% reduction in text, 2 videos, 97 graphics, and 4 interactive widgets. Additionally, in iteration 2, we made the conversational prompts and questions more explicit, as well as better directing the users to engage with the On the Move activities.

Focus on one Discovery Spot

Since the addition of a sketchpad widget at Discovery Spot #3 in iteration 2 was the most drastic change made to the e-Trailguide between iterations, we isolated Discovery Spot #3 in order to compare engagement patterns between iteration 1 and iteration 2. As a result, we noted that instances of heads-up observations and pointing increased substantially, while tactile investigations were subdued in both iterations (Table 3).

We saw that in iteration 1, where children were presented with text and images about trees at that location, there were 62 instances of heads-up observations and 16 instances of pointing at the trees around them. In iteration 2, the sketchpad widget was added to the e-Trailguide's content in order to further engage children with the trees by asking them to choose a tree and draw it using the widget. Adding this feature to the e-Trailguide resulted in increased heads-up observations (149 instances) and moments of pointing (37 instances).

The amount of time spent at Discovery Spot #3 also increased between iterations 1 and 2. In iteration 1, the average amount of time spent at Discovery Spot #3 was 2.9 minutes; during iteration 2, this time tripled to an average of 9 minutes. Given the noticeable increase in the amount of time spent at Discovery Spot #3 in iteration 2, it is not surprising that there would be more instances of engagement with nature. However, because we were designing the e-Trailguide to act as a facilitator for observing the local landscape, we assert that increased time coupled with increased engagement were two important components for providing an active learning experience for children along the nature trail. Additionally, because we found that the types of engagement were sequenced in a step-wise fashion, we posit that spending more time at certain junctures along the trail may lead to one participating with different levels of engagement.

Discussion

Our DBR study featured two iterations of a self-guiding e-Trailguide that looked at the use of this mobile technology as a stand-alone facilitator of learner engagement with nature along a nature trail. Through the documentation of two iterative cycles of enactment and revision, we were able to deduce similarities across both iterations with regard to technology-mediated engagement with nature, as well as differences in instances of engagement between iteration 1 and iteration 2. From our analysis presented above, three implications were derived that we discuss in this section—one related to design, one related to the theory of engagement, and one related to the methodological role of our analytical framework.

Designing for technology-mediated engagement with nature to support science learning

Previous research on mobile learning in museums (Hsi, 2002; Lyons, 2009) provided the initial guidelines that motivated the design of the SCEC e-Trailguide. Building from this work and as a result of our research, we derived three design guidelines for mobile computers integrated into outdoor informal programs to support science learning about the natural world:

(1) inclusion of textual prompts and questions pertaining to the immediate setting and related natural objects in order to facilitate observation,
(2) development of joint observational challenges or activities that occur along a stretch of trail to encourage collaborative learning (as evidenced through pointing), and,
(3) articulated directions and/or instructions to promote tactile investigations of natural objects.

We offer these guidelines, described in the following sections, as starting points to science educators wishing to engage learners in out-of-school technological-enhanced activities.

Inclusion of textual prompts and questions pertaining to the immediate setting to facilitate observation

First, heads-up observations among the children in our study was a frequent type of user interaction we observed from the video-records. While Rogers and Price (2008) have documented the ability for school children to integrate information from mobile devices with real-world observations of woodland biota, our work articulates the mobile design elements that facilitate this type of engagement with nature. Based on our study, we noted that designing the e-Trailguide to include textual prompts and questions that were place-based and therefore, pertained to the surrounding landscape, resulted in children using the mobile media to further observe their surroundings along the nature trail.

Development of on-the-move joint activities to encourage collaborative learning

A second form of science engagement that was commonly seen as the children used the e-Trailguide on the trail was the act of pointing. Because learners who gesture are more likely to remember what they have learned from a task when compared to learners who do not gesture (Cook, Mitchell, & Goldin-Meadow, 2008), we believe that the high frequencies of pointing amongst the research participants was a positive outcome of using the e-Trailguide. We noticed numerous instances of pointing throughout both iterations, especially during the On the Move activities. Because these activities were intentionally designed to challenge users to seek out and observe certain aspects of the landscape, pairs sharing an iPad often worked together to achieve these challenges. These collaborative learning moments were important to recognize, especially when one considers Brody's concept of learning in nature (2005), where he argues that in order for meaningful learning to take place, an individual must be interacting with others. More specifically, pointing emerged as being an important social indicator of the learning and communication going on between the children. In the informal learning setting of an indoor science museum, Meisner et al. (2007) observed that physical movements among visitors became important modes of demonstrating one's sense-making and assisting with others' learning experiences. This resonates with the instances of pointing in our study as pointing was often a strategy used between two children to explain and show where a certain object in the forest was located if one partner had difficulty finding or observing the object.

Articulated directions to promote tactile investigations of natural objects

Lastly, we observed that tactile investigations of natural objects, either with one's hands or with the iPad, were less common amongst the children in our study. Specific On the Move activities encouraged a more hands-on exploration of the natural phenomena along the trail, including one that challenged children to match colors in the e-Trailguide to colors found in nature. Although we did not see many instances of tactile investigations, other researchers argue that creating opportunities for 'sensory engagement' in the outdoors is critical for students during environmental education programs (Ballantyne & Packer, 2009). In a study at an arboretum, Zimmerman and colleagues (2015) documented the ability for mobile devices to facilitate closer inspections of the trees onsite, including physical explorations of parts of the trees, like the bark. Physically examining the trees was not intentionally designed into their mobile learning program; instead, the tactile investigations were a reaction to the content being displayed and the learners' curiosities of the real-world trees nearby. Similarly, in our study, tactile investigations of natural objects along the trail seemed to occur by chance. It may be for this reason alone that the third level of engagement was so rare. If tactile learning is the desired outcome, we suggest that more directional and articulate instructions must be given.

Designing for engagement opportunities

When we compared engagement levels at Discovery Spot #3 between iterations 1 and 2, there was a noticeable increase in the amount of instances of observation and pointing in the second iteration (Table 3). Additionally, the amount of time spent at Discovery Spot #3 increased from an average of 2.9 minutes in iteration 1 to an average of 9 minutes in iteration 2. Some museum researchers argue that the more time one spends with an exhibit, the more meaningful their engagement (Humphrey & Gutwill, 2005; Yoon, Elinich, Wang, Steinmeier, & Van Schooneveld, 2012). A different angle posits that high levels of engagement and interaction with an exhibit often lead to a prolonging in the amount of time one spends with that educational content (Sanford, 2010). Given these findings from museum research and the findings from our study, we argue that carefully designed mobile learning applications can instill the same types of prolonged science engagement in outdoor settings that exhibits promote in designed, indoor museum spaces.

An analytical framework for understanding engagement in the outdoors

As we demonstrated in our review of the literature, there have not been any studies that have documented the engagement patterns between the learner and the natural phenomena when a mobile tool is incorporated into the learning activity; therefore, our work provides others with a needed description of what it means to be engaged with one's surroundings in an outdoor setting. We provide the technology-mediated engagement with nature conceptual framework as a useful analytical framework to code science learning data related to the natural world and outdoor-based technology designs. This framework can be used by researchers who seek to understand learner engagement with science in the natural world. Additionally, this framework makes a necessary advancement to the concept of engagement with nature as it considers pointing to be an important indicator for learning when mobile devices are mediating the educational activity. Our framework supports Rahm's position on learning in informal settings where 'meaning-making is too often equated with linguistic meaning' (2004, p. 225) and that nonverbal gestures also constitute conversational meaning-making between learners.

Advancing the concept of engagement in out-of-school settings

A final contribution of this study is the creation of an empirically grounded account of engagement as observed on the trail of SCEC. The leveled pattern of engagement as demonstrated by a child in our study typically followed these steps: first, they were prompted by text or activity directions in the e-Trailguide; second, this information facilitated them to look up and observe their surroundings; third, they pointed to an object along the trail; and fourth, the children engaged in a deeper exploration of the object by physically examining it with either the iPad or their own hands. While this pattern of events was not intended when we initially designed the e-Trailguide, we believe that this is an important finding that can be used to compare learning in various settings. In particular, does this same sequence of events occur in outdoor learning without the presence of a mobile device? Would different social groups (i.e. families, adult groups) display the same sequence? Understanding why these patterns of engagement occur in outdoor spaces and how to best facilitate engagement can aid outdoor educators in providing science learning experiences for a variety of audiences. This finding enhances our conceptions of peer engagement in the outdoors to show that certain forms of interaction may proceed and follow others. This has relevance to both learning scientists understanding how people learn science in outdoor space and to designers who may want to plan for a similar step-wise engagement.

Concluding recommendations for informal technologically enhanced pedagogy

For environmental education centers that wish to engage their visitors with nature in a meaningful way, we found that providing an e-Trailguide in the form of an electronic book for children attending summer camp was an effective means of fostering learner engagement in the outdoors. To support science engagement, we recommend the inclusion of purposeful textual prompts and questions to heighten observations, challenges in the form of on the move scavenger hunts or other joint activities, and widgets to provide visitors with an opportunity to observe and reflect on what they see in their surroundings. With a mobile technology designed to foster engagement with the natural world, the children in this study were not only engaged through heads-up and hands-on opportunities in the outdoors, but they also participated in an enjoyable means of exploring nature. In this way, we believe that the participants also took part in a 'hearts on' learning experience (Sipos, Battisti, & Grimm, 2008) where they were emotionally immersed and personally connected to the natural wonders of their own local ecosystem.

A challenge for environmental educators is introducing mobile learning in such a way that it enhances people's experiences outdoors, rather than creating a dependency on the device's screen. This study, which focused on the implementation of a mobile learning design set within a forested trail, elucidated the patterns of engagement between learners and the natural world when a mobile learning tool in the form of an electronic book was introduced. Through the enactment, analysis, and re-design of an e-Trailguide with 83 children attending summer camp, we developed a new framework related to technology-mediated engagement between learners and their natural surroundings, three specific types of engagement fostered by the e-trailguide, and a learning pattern with regard to the types of engagement. Results from these two iterations provide important design considerations with regard to the types and amounts of photographs, texts, and interactive widgets that can support different kinds of learner engagement. Future directions for research that resulted from this study include examining social patterns and forms of engagement when a mobile device is introduced into an outdoor-based learning experience for other groups of learners, such as families.

Note

1. Conifers are trees that are cone-bearing trees, such as pine trees, spruces, and hemlocks.

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