Education Tech Research Dev
DOI 10.1007/s11423-015-9369-6

DEVELOPMENT ARTICLE

Socio-technical dimensions of an outdoor mobile learning environment: a three-phase design-based research investigation

Susan M. Land · Heather Toomey Zimmerman

Abstract This design-based research project examines three iterations of Tree Investigators, a learning environment designed to support science learning outdoors at an arboretum and nature center using mobile devices (iPads). Researchers coded videorecords and artifacts created by children and parents ($n = 53$) to understand how both social and technological supports influenced observations, explanations, and knowledge about trees. In Iteration 1, families used mobile devices to learn about tree characteristics and identification in an arboretum; in Iteration 2, families used our mobile app about trees' life cycles and completed a photo-collage task documenting life cycle phases; Iteration 3 used a refined version of the Iteration 2 mobile app with children at a nature center summer camp, along with customized tools embedded into the app for documenting photographic evidence of tree life cycle phases in the forest. Findings suggested: (a) learners engaged in science talk representing observation and explanation practices (perceptual, conceptual, connecting, affective talk), and varying learning conversational patterns emerged based on refinements to design implementations; and (b) making connections between concepts introduced on the mobile app and application of them outdoors was challenging for learners without explicit social and/or technological support during identification tasks; specifically, appropriation of scientific vocabulary, noticing relevant features, and accurately identifying life cycle stages needed structured, on-demand support. Findings point to empirically-based implications for design of socio-technical supports for mobile learning outdoors.

Keywords Mobile computers · Mobile learning · Learning technologies · Informal education · Family learning · Socio-technical system

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Published online: 26 February 2015

Advances in mobile technology have led to conceptualizations of learning that entail new forms of engagement that are afforded by on-demand, contextualized, and media-rich interactions (Sharples 2010; Squire and Klopfer 2007). Mobile learning perspectives are shaped by the overarching view that mobile computers afford contextual sensitivity to, and hence potential seamlessness with, people's activities (Milrad et al. 2013; Sharples and Pea 2014). Context-sensitive learning (Sharples), also referred to as context awareness (Dunleavy and Dede 2014), suggests that natural settings, when augmented by mobile resources, can foster different kinds of learning interactions and experiences. Sharples (p. 4) offers the following multi-dimensional illustration of context-sensitive learning:

> Consider a group of children on a field trip to a museum. One child in the group is holding a multimedia guide and they are all viewing and discussing a museum exhibit. Their learning context embraces not only the location and museum exhibit, but also interactions between the children and material on the multimedia guide, the conversation of the children, their prior knowledge of the exhibit and its personal, cultural and historical meaning, the route that each child has taken through the museum to arrive at the exhibit, and people around them including museum guides, teachers, and other children. Their context is continually unfolding, as they move, talk and engage with the surroundings of the museum to create personal and shared meaning…

It is worth highlighting that Sharples' conceptualization presumes that context encompasses more than solely location; instead, he suggests that, by moving computational tools off the desktop and into the world where people participate in activities, rich opportunities for distributing learning across socio-technical systems of people, artifacts, technologies, and environment are afforded. In this view of context-sensitive learning, activities and thinking are mediated by designed artifacts and social interactions within the educational environment.

Socio-technical systems have been discussed within the socio-cultural perspective of distributed cognition (Hutchins 1995) and distributed intelligence (Pea 1993). Distributed intelligence/cognition analyzes learning as change within a socio-technical system (Halverson 2002; Hutchins 1995), where individual minds are one part of a learning network. In distributed cognition, thinking is accomplished with both internal mental resources and external resources in one's environment, including technologies, language, inscriptional systems, and other people. Pea (1993) acknowledges that distributed intelligence is not a design theory, per se; rather, it is a "heuristic framework" (p. 48) that has theoretical implications about design of technologies for learning. Pea suggests that designers can leverage distributed intelligence by augmenting dimensions of the socio-technical system that shape what activities are possible to accomplish, such as augmenting with computing, with human guided participation and cultural tools, and inscriptional systems. These theoretical dimensions hold design implications for directing the activities of learners, because these augmentations exploit the configuration of social, material, technological, and situational resources of their environment (Pea; Pea et al. 2008).

Theoretical framework for the present study: conceptualizing a socio-technical system for mobile learning outdoors

We have conducted a series of design-based research projects (Zimmerman et al. 2015) to design mobile technologies to augment scientifically-meaningful experiences for youth and families during their out-of-school time in outdoor informal learning institutions (ILIs) (Bell et al. 2009; Falk and Dierking 2000). Across our projects, we support children and families to become (a) scientific *observers* who can coordinate science knowledge with their sensory experiences in the outdoors and (b) *explainers* of scientific phenomena related to ecology. We adopted mobile computers to accomplish these two learning goals given the increasing ubiquity of tablet computers and smart phones in everyday life (Warschauer and Matuchniak 2010) and increasing presence of tablet computers and smart phones in the lives of families with modest socioeconomic means (Yardi and Bruckman 2012).

Our research builds on the framework of distributed intelligence (Pea 1993). We use distributed intelligence as a theoretical lens to understand how youth and their families think about trees based on the their interactions with mobile devices, each other, and a Naturalist present onsite at an arboretum and nature center. We also draw upon the related framework of distributed scaffolding (Tabak 2004) to design strategies for supporting learning in human-technical systems. Distributed scaffolding coordinates different types of support (Tabak) across people, artifacts, and environment, so that scaffolds reside across a range of technological and human sources. From Reiser and Tabak (2014), we infer the relationship between distributed intelligence and disciplinary thinking is the following:

> With distributed scaffolding, a variety of material and social tools with different affordances and constraints can be employed strategically to provide the large assortment of support learners need to develop disciplinary ways of knowing, doing, and communicating (p. 193).

Consequently, we include multiple strategies to concurrently support learners to observe and explain science concepts. Pea (2004) and Tabak suggest that designed supports can be conceptualized as (a) scaffolds to support learning new activities and practices with an intention to fade over time or (b) tools for distributed intelligence supporting thinking during activity (i.e., a scaffold that does not fade). In this regard, our work included coordinated tools for supporting learners during complex activity, across human and technological sources. Due to constraints in the amount of time we had available with children and families, our studies did not fade the scaffolds.

Adapting Pea's (1993) dimensions for augmenting learning, and taking into consideration that context-sensitive mobile learning affords unique types of interactions among people, technology, and the environment (Fischer and Konomi 2007; Luckin 2010; Milrad et al. 2013), we applied the following framework to conceptualize socio-technical considerations in our research. Figure 1 presents a four-pronged analytical framework for mobile learning research and design: (1) augment using technology; (2) provide guided participation; (3) integrate the environmental setting into the design; and (4) leverage learner's prior knowledge, beliefs, attitudes, and values.

It is important to note that the setting we are exploring is an informal learning setting that has unique factors that affect the configuration of our socio-technical design. First, our work is situated firmly in out-of-school time. Being situated in out-of-school means that participants come to the informal learning setting with varied ages, interests, and background knowledge in contrast to a single-age classroom. For instance, a family could consist of a parent who enjoys science, a parent who does not like science, a 4-year old who has not yet been to school, and a 10-year old who together explore the informal learning setting as an intergenerational unit. Likewise, visiting the informal learning setting is voluntary—families choose to come to an Arboretum or Nature Center with their own goals for leisure or education from the space. Families' unique goals and agendas affect the

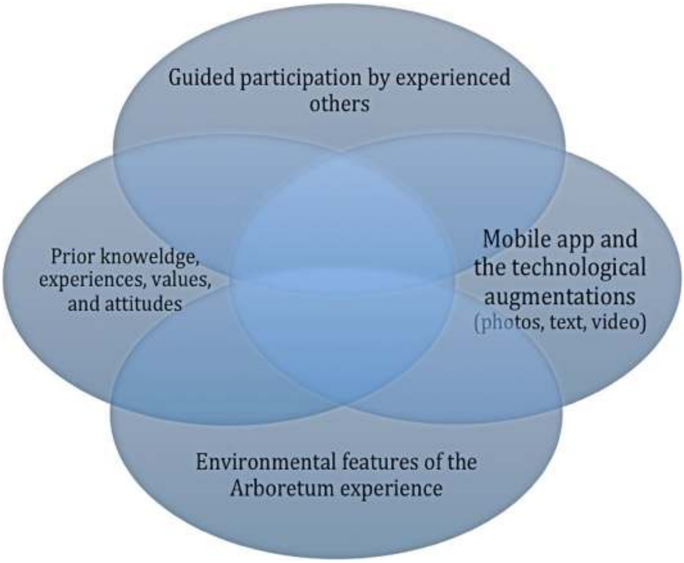

Fig. 1 Socio-technical theoretical framework for Tree Investigators research and design

time and resources available to deeply engage the learning opportunities of the space (Zimmerman et al. 2010b). Likewise, children attending summer camp often work with parents to select a topic based on their personal hobbies, interests, and expertise (Zimmerman and Bell 2014). Given these unique attributes of out-of-school learning, it is important to investigate how learner's participation in science practices in informal settings can be advanced through design of socio-technical systems. A brief summary of each socio-technical dimension is presented below, with more detailed strategies discussed in the methodology and findings sections.

Augmenting thinking using technology

To help them look deeply at the natural world, people need support in observation, identification, articulation, and explanation-building practices (Eberbach and Crowley 2009; Lehrer and Schauble 2006; Zimmerman et al. 2013). Our research uses technological supports for science learning using mobile devices (Chen et al. 2005; Land and Zimmerman 2014; Liu et al. 2009; Rogers et al. 2004; Squire and Klopfer 2007; Tan et al. 2007) to support science inquiry (Land and Zembal-Saul 2003; Quintana et al. 2004). Prior mobile learning studies in outdoor settings have augmented the natural space to enhance access to information, record field observations, search databases to identify species present, and to personalize learning (Chen et al.; Rogers et al.; Zimmerman and Land 2014). In some projects, the mobile technology serves a stand-alone role for self-guided exploration of specimens. For instance, Chen et al. developed a mobile image-retrieval system to support bird watching and butterfly watching, with the goal of simulating the learning support provided by a naturalist. Likewise, Liu et al. used mobile devices for learners in Taiwan to learn more about ponds using close-up images and detailed information tied to aquatic plants in the habitat. Research findings across these studies demonstrated that learners increased factual knowledge of plants (Liu et al.), identification skills (Chen et al.), engagement with nature (Rogers et al. 2004) and conceptual understanding (Liu et al.)—suggesting that augmenting natural settings with technology can enhance learning.

Augmenting thinking through guided participation

Guided participation (Rogoff 2003) is a concept from sociocultural psychology that examines how elders, parents, and teachers participate in co-constructing human development with children. Rogoff considers the way that others help youth bridge meanings and structure participation to enable learning mediated through observation, talk, and other forms of engagement. Informal learning research has shown that parents can guide youth's participation by generating interest and collaboratively building knowledge (Crowley and Jacobs 2002; Zimmerman and Bell 2014; Zimmerman et al. 2010a). Our project uses experienced Naturalists to help people see the scientifically-relevant aspects of trees. We posited that the Naturalists would support families' conceptual development of ecological constructs because prior work has shown that children learn more science when going through an ILI with an adult than alone (Fender and Crowley 2007), but parents can miss opportunities to support the children fully in scientific reasoning (Gleason and Schauble 2000).

The role of the environment

Learning research in ILIs has focused on the ways that people learn with and from objects in environments (Bell et al. 2009; Paris 2002). Research has found when people are learning to make scientific observations, novices need support to see the object and its related phenomena in scientific ways (Eberbach and Crowley 2009). At the same time, observational investigation has a complexity that is often not acknowledged (Smith and Reiser 2005)—observing objects as scientific relies on discipline-specific tools for sense making and theory articulation (i.e., building explanations) that require time to develop (Eberbach and Crowley). In settings such as botanical gardens, learners face an even greater scientific challenge: a dynamic, unpredictable environment where specimens appear in varied forms and shapes according to seasonal timelines. Learners need to understand what is relevant scientifically in an ever-changing situation, where, for example, a tree may have flowers on one visit but none on the next visit.

Learner's prior knowledge, experiences, values, and attitudes

In the distributed intelligence perspective, individual social and cognitive resources play an important role in learning. The focus on the learners in a distributed cognition framework takes a holistic view of factual, procedural, heuristic, and conceptual knowledge along with learners' values, attitudes, and prior experiences (Bell et al. 2009). Prior knowledge is important in environmental learning (Heimlich and Falk 2009), given that new ideas are integrated into prior knowledge in the process of conceptual development (Ivarsson et al. 2002). Other research has found that learners' goals affect the knowledge, values, and attitudes that arise from participation in out-of-school science activities (Falk and Dierking 2000; Polman and Miller 2010; Zimmerman and Bell 2014). The learner's prior knowledge, experiences, values, and attitudes both influence other aspects of the socio-technical system and are changed as an outcome of participating in the system.

Research purpose

Our overarching methodology is design-based research (Hoadley 2004; Sandoval and Bell 2004; Sandoval 2014), which informs design, theory, and practice concurrently through iterative implementations. We conducted three iterations of research and development around questions of how to support "heads-up" interactions (e.g., Hsi 2003) within a rich outdoor setting using socio-technical design considerations for mobile technologies. Our research team worked for over 4 years to establish partnerships with a local University arboretum and for 6 years with a Nature Center on educational programming. We beta tested mobile technology prototypes with hundreds of children visiting our University arboretum. From our beta tests, we developed a technological infrastructure that we iterated for in-depth research.

This paper discusses the design, research, and re-design of three iterations of a mobile learning project that took the form of three collective case studies (Stake 1995) to understand how families talked about science while interacting with our socio-technical program. Our research investigated the following questions:

- How do people talk together about trees and life cycles in an outdoor learning environment designed using socio-technical theory?
- What elements of the socio-technical system influenced various types of science talk?

Methodology

Participants and setting

Across the three iterations of research and design, 53 people participated. The participants in Iteration 1 were 25 people from 11 families (children 6–11 years old); Iteration 2 had 15 people from 6 families (children 6–12 years old); and Iteration 3 had 13 children from 12 families (9–12 years old). Given that we designed our program for users of informal sites, we strategically recruited current users of a nature center for intergenerational education and recreation.

The site for Iterations 1 and 2 was a University Arboretum in the Northeast United States, the Arboretum at Penn State, which includes groomed gardens and a stand of old-growth hardwood forest. The oldest trees in this grove pre-date construction of the University in 1859 and as such, the grove holds a protected status due to its historical and cultural value. Iteration 1 used only the groomed gardens while Iteration 2 used both the groomed gardens and the old-growth forest. Inclusion of the forest allowed for learners to see trees in all five stages of the lifecycle (e.g., seed, seedling, sapling, mature, dead). Iteration 3 was held at the same University's nature center, Shaver's Creek Environmental Center during a summer camp, which abuts 7000 acres of public access forests in Northeast Appalachia with trails, raptors, and interactive displays. Study 3 was conducted without the accompaniment of a parent; instead, a camp leader and two high school interns (in addition to the naturalist) served as more the knowledgeable others. Iteration 3 took place on hardwood forest trails with similar species to the Arboretum forested site in Iteration 2.

Socio-technical design strategies across the three studies

Sandoval (2014) presents a DBR research framework for mapping theoretical conjectures to design structures (embodiment), mediating processes, and outcomes for design-based research, extending earlier calls for systemic validity (Hoadley 2004) or alignment of theory, design, interpretations, and practice. Our DBR approach "…documents what has been designed, the rationale for this design, and the changing understanding over time…" of initial theoretical conjectures (Hoadley 2004, p. 204). Our overarching theoretical perspective comes from the presumption that learners are engaged in a socio-technical system where the technology, people, and setting all contribute to learning. Consequently, our design was conceptualized holistically as a learning environment—rather than a standalone mobile app—that was comprised of guided participation with a naturalist, technologically-mediated resources from a mobile app, sensory experiences on-site with trees, and social interactions with others as needed for learning. In this section, we discuss each of our orienting design conjectures, highlighting the strategies deployed by the mobile technology and the naturalist. Table 1 summarizes these conjectures with associated strategies, which are elaborated further in the section discussing each DBR iteration.

Across all iterations, a naturalist guided people to observe trees and to coordinate their observations with scientific information delivered by a mobile device. The naturalists were qualified (M.Ed., M.S.) instructors of environmental education or plant sciences at our University and were members of our research and development team from the outset. To enact the theory within our design, the naturalist worked from a script that detailed questioning strategies and activity sequences for the learning environment (discussed in next section). The naturalist led groups of 5–10 learners at a time through a tour lasting approximately 1 h. All studies utilized iPad 2's or iPad Mini's to provide content information tied to specimens at the site, and to augment seasonally or developmentally unavailable characteristics of trees via digital photographs and text. The naturalist directed learners as to when and how to use the mobile materials. A Ph.D-level and a M.S. level botanist reviewed the content presented within the socio-technical system for scientific accuracy. Screen shots of our mobile learning interface are depicted in Figs. 2 and 3 and described further in the sections that follow.

Design conjecture 1: support learners to make scientific observations outdoors

The mobile technology served three main purposes to support observations. First, we designed digital resources to channel the learners' attention (Pea 2004) to specific features of the environment that highlight disciplinary concepts (Quintana et al. 2004). Without a foundation of disciplinary knowledge, it is difficult for novices to know what is relevant to attend to in a complex setting (Eberbach and Crowley 2009; Land 2000; Smith and Reiser 2005; Zimmerman et al. 2013). In response, we designed text and photographs to assist learners to notice the features of the environment needed for discerning types of trees and the stages of a tree in its life cycle. For instance, we provided photos of a prototypical example of a pine seedling, bark texture, and leaf size and shape. Likewise, we provided contrasting images that revealed important visual distinctions (Bransford et al. 2000) that might otherwise go unnoticed (e.g., different branching structures). Second, given that the outdoor landscape is constantly changing in response to the seasons, weather, growth variations, and animal migration patterns, it is impossible to observe all important characteristics of trees in one visit to an informal site. Accordingly, we provided images to help

Table 1 Socio-technical design elements across the 3 DBR iterations of *Tree Investigators*

Design conjecture 1: support learners to make scientific observations outdoors			
Mobile technology strategies	Naturalist guided participation strategies	Environment	The learner
Digital resources were designed to channel the learners' attention (Pea 2004) to specific features of the environment that highlight disciplinary concepts (Quintana et al. 2004): Text and photographs to assist learners to notice relevant features of the environment (e.g., photos illustrating a prototypical example of a pine seedling); Contrasting images that revealed important visual distinctions for identifying what is scientifically relevant that might otherwise escape attention (e.g., contrasts in branching structures) (Bransford et al. 2000) *Photos/images were provided to help learners visualize non-visible scientific elements of the gardens/forest (Rogers et al. 2004):* Photos of tree characteristics across seasons; Photos of features that cross seasons and/or life cycles that might not be present at the same time in a place (e.g., pine cone at different stages of releasing seeds)	The naturalist provided expert guidance to prompt deliberate comparison of on-site observations to the digital resources of the app (Liu et al. 2009) that might explain them (e.g., "Comparing the photograph in the app, look at this tree in front of us. Does it look like a seedling? Why do you think this?"); The naturalist encouraged science-related conversations of features found in the environment for which learners express interest (Eberbach and Crowley 2009; Zimmerman, et al. 2013); The naturalist prompted open-ended questions about what learners were noticing ("what are some things you notice about this tree?")	Mobile technology content and naturalist interactions were focused on specific characteristics of the local environment (e.g., "look halfway up the tree trunk to see the bark pattern")	Learners engage multi-sensory experiences (point, look, touch) (Salman et al. 2014) to encourage "heads-up interactions" (Hsi 2003); Learners ask questions to each other and the naturalist about what they observe

Table 1 continued

Design conjecture 2: use child-centered designs for mobile learning			
Mobile technology strategies	Naturalist guided participation strategies	Environment	The learner
Mobile technology strategies were designed so children, not just the adults, have access to the scientific information (Zimmerman and Bell; Zimmerman et al. 2013; Zimmerman, Perin, et al. 2010a, b): Use of photographs, line art, and simple text to allow children to access disciplinary perspectives; Limit amount of text presented so that learners do not revert to "schooling" mode of interaction; When text is used, it was written at third grade level	The naturalist scaffolded disciplinary conversations; The naturalist began the activity with questions to solicit prior knowledge and then posed a driving question tied to surroundings (e.g., "who has planted a tree before? Look around at all of these trees in this forest. How do you think trees like this grew here? Did someone plant them?")	Specimens in environment are central in activating prior knowledge and in learner-directed investigations	The children hold and read from devices; Learner-initiated interests and interactions are supported
Design conjecture 3: use conceptual models (Quintana et al. 2004) across activities versus discrete factual knowledge tied to singular objects.			
Mobile technology strategies	Naturalist guided participation strategies	Environment	The learner
Mobile application used a conceptual organizer (Quintana et al. 2004) of the tree life cycle to illustrate concepts present in the setting that extends across specimens: All mobile materials were indexed via either the life cycle (Iterations 2 and 3) or tree characteristics (Iteration 1) organizational scheme; Mobile resources presented the conceptual organizer across specimens (e.g., oak and pine tree life cycles); Tools and pedagogy supported applying concepts across settings (groomed gardens vs. the forest) (Iterations 2 and 3 only)	*Naturalist strategies included prompting learners to compare observations across species to see how the concepts were embodied in the environment ("How are the leaves different from the pine tree we saw?"):* Guide transition from a structured environment (pre-selected, groomed trees) to a more complex and natural setting with new species and elements not previously encountered (forest)	Multiple elements or specimens across the natural environment are intentionally explored	Learners extend what has been learned from one situation to a new one

Table 1 continued

Design conjecture 4: scaffold complex disciplinary practices in natural settings			
Mobile technology strategies	Naturalist guided participation strategies	Environment	The learner
Mobile technology strategies included structuring complex tasks (Quintana et al.) required for engaging in science practices of observation, identification, and explanation: Identification scheme is simplified to 3 characteristics for each tree (Iteration 1 only); Learners use digital cameras to capture observations and make them visible; Mobile app included tools for organizing photographic representations into artifacts (Iterations 2 and 3); Photo-capture/annotation tool was developed to provide just-in-time support for linking identification practices with observable criteria or evidence. (iteration 3 only)	Naturalist strategies included guiding the progression of activities across various locations in the environment; Naturalist prompted learners to provide evidence or criteria for their observations, identifications, or explanations	The complexity of the natural environment is initially constrained, but in a culminating activity, it is more fully included	Learners help each other evaluate evidence for identification; Learners progressively increase responsibility for learning

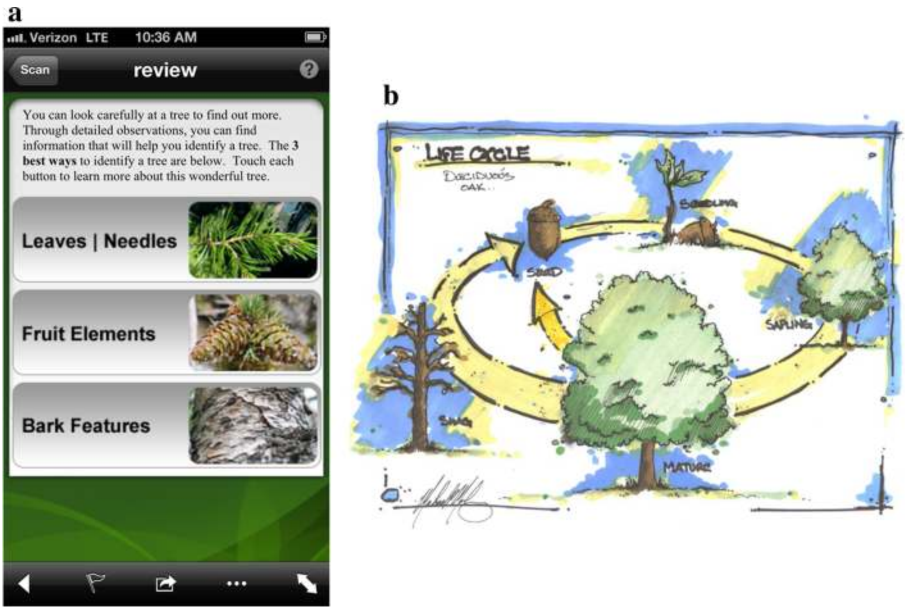

Fig. 2 **a** Mobile app design for Iteration 1: tree characteristics. **b** Mobile app design for Iteration 2: conceptual model

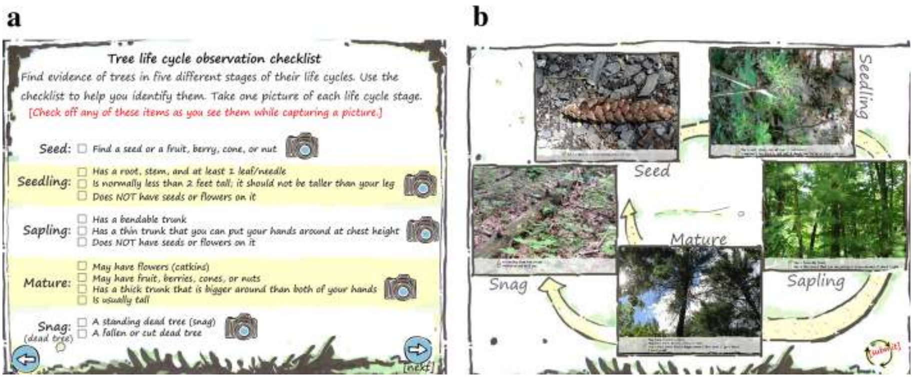

Fig. 3 **a** Iteration 3 photo capture and annotation. **b** Iteration 3 example photo collage

learners visualize non-visible scientific elements of the gardens or forest (Rogers et al. 2004), such as tree characteristics across seasons and life cycles stages.

The role of the naturalist in aiding learners to make scientifically-relevant observations is to provide contextualized expert guidance (Linn and Slotta 2000) using prompts, questions, and modeling (Ge and Land 2003; 2004). First, the naturalist prompted deliberate comparison of on-site observations with the digital resources (Liu et al. 2009) that might explain them (e.g., "Looking at the photo on the iPad and this tree in front of us. Does it look like a seedling? Why do you think this?"). Our goal was to use the mobile materials and the naturalist to channel the learners' attention (Pea 2004), so that they are engaged in conversations related to both their own observations and science concepts (Eberbach and Crowley 2009). Second, the naturalist encouraged conversations about unplanned observations in the environment for which learners express interest (Eberbach and Crowley). For example, one learner found an acorn that had begun to sprout a stem, and the naturalist showed the entire group this characteristic as well as inferred why or how it was uprooted. Third, the naturalist prompted learners with open-ended questions about what they were noticing ("what are some things you notice about this tree?") in order to reveal learners' initial observations and to model observational practices. As such, the naturalist played an important role in interleaving learners' formative ideas, technology materials, and the environment.

Taken together, mobile technology and naturalist interactions were focused on specific characteristics of the local environment (e.g., "look halfway up the tree trunk to see the bark pattern shown on the iPad"). This systems approach to include human and technological supports was designed to engage learners in multi-sensory experiences (point, look, touch) (Salman et al. 2014; Zimmerman and Land 2014) and to interact with each other about what they observed.

Design conjecture 2: use child-centered designs for mobile, informal learning

Research in informal learning settings (Crowley and Jacobs 2002; Zimmerman et al. 2010b) has shown that children, not just parents, can have high levels of interest and expertise about the science topics explored together. Families engage in mutual knowledge building with various family members supporting each other (Palmquist and Crowley 2007; Zimmerman et al. 2013). Mobile technology strategies included providing access to scientific content related to the setting using representations that children can engage, such as images. Specifically, we included realistic photographs that focus on key scientific features along with hand-drawn conceptual elements that created visualizations of the relationships between the ecological cycles and learners' observations of the environment. When text coincided with the image, we limited the text to two to three short sentences. This ensured that materials were written at a third-grade reading level as measured by the Flesch–Kincaid score so that the upper elementary and middle-school children could read the information (third grade is between 8 and 9 years old in the USA).

The naturalist's role included modeling and scaffolding disciplinary strategies, practices, and explanations, using available features in the environment (Pea 2004). The naturalist modeled, for instance, how to locate seeds in a pine cone specimen that was still closed. Naturalists played an important role in supporting on-demand learning in ways that could not be readily predicted in advance, such as monitoring and correcting when learners focused on irrelevant observations, and elaborating concepts introduced in the mobile materials. The naturalist solicited prior knowledge through questioning strategies and connected those ideas to the concepts being explored. For instance, in Iteration 3, the naturalist began the activity with questions to solicit prior knowledge related to the driving question of "how do trees grow up in the forest?" (e.g., "Who has planted a tree before? Look around at all of these trees in the forest. How do you think these trees grew here? Did someone plant them?"). In this way, the naturalist engaged with children's initial conceptions, tied them to the surroundings, and built upon them throughout the mobile-enhanced experience.

Design conjecture 3: use conceptual models (Quintana et al. 2004) across activities versus discrete factual knowledge tied to singular objects

This design conjecture assumes the need to scaffold learners to make explicit connections between what they observe and broader ecological concepts. One mobile technology strategy we used to foster conceptual connections across specimens was the inclusion of a graphic organizer (Quintana et al. 2004) of the tree life cycle for two species (pine vs. oak) (Fig. 2b). This provided an implied structure to the content flow from seed to seedling to sapling to mature tree and then to snag, allowing learners to recognize how each step of the life cycle was connected to other steps as well as the whole life cycle. In contrast to mobile learning approaches that provide content tied to objects (e.g., audio about a specific object at a museum), we sought to support broader conceptual applications across multiple objects and settings.

We designed naturalist-led sequences of activities to apply concepts across species in the Arboretum as well as across settings. For example, learners investigated tree life cycle concepts while looking at two contrasting tree types—an oak tree (broadleaf and deciduous) and a pine tree (needle leaf and conifer)—examples that looked different from each other at each life cycle stage (e.g., a pine tree grows from seeds within a pine cone and an oak tree grows from seeds within an acorn) but were related conceptually (e.g., both trees grow from seeds). Learners then were guided from the more structured garden environment that used pre-selected trees to a more complex forest setting with new species and elements not previously encountered. Specific strategies employed by the naturalist included prompting learners to compare observations across species (e.g., "how are the leaves different from the pine tree we just saw?").

Design conjecture 4: scaffold complex disciplinary practices in natural settings

We incorporated strategies and tools that enabled learners to participate in complex practices of identification that normally would have been challenging or imprecise without such support (Pea 2004). One form of mobile technology support included making identification practices explicit during learners' interactions with the mobile resources (Quintana et al. 2004). For example, as shown in Fig. 2a, our first mobile design used an identification scheme that was constrained to the 3 most salient characteristics that scientists would use to identify a tree. We also used existing tools (e.g., tree ID app) or developed customized tools to support learners to capture and annotate photographs of their observations in order to make their thinking visible. In Iteration 3, we designed a photo-capture tool directly within the mobile app (see Fig. 3a, b), which also included a checklist of observations that were superimposed onto learners' photographs of trees in various life cycles (described in more detail later). These elements supported learners during minimally-structured, independent explorations in the forest to both identify trees at their life cycle stages and to document and share them with the group and naturalist. This provided a method for the naturalist to monitor what learners were observing and interpreting. The naturalist guided the progression of activities across various settings and prompted learners to provide evidence for their identification.

Video-based data sources and analyses

In keeping with our qualitative DBR study design, our primary data are observational records. All families and children were videorecorded during their guided tours and follow-up interviews. We collected 10.5 total hours of video across all iterations. Video data were transcribed line-by-line and analyzed to elucidate how socio-technical elements of the mobile learning environment supported people in scientific observations and explanation-building talk as they explored the outdoors. Video records were collected and analyzed in keeping with recommendations for learning sciences research (Derry et al. 2010). We used Allen's (2002) coding framework to analyze transcripts for evidence of observational and explanation-building talk (described later). These coded aspects of the transcripts were considered with all four aspects of the socio-technical activity: the scaffolds and augmentation from the mobile technology, the augmentations provided verbally as guided participation from the Nature Guides, the individual contributions, and the natural environment of the Arboretum.

In accordance with the collective case study methodology, each iteration was considered as a case. These three iterations (cases) can be compared qualitatively; however, given the exploratory nature of this work and the differences in study populations, controls were not employed for statistical comparisons between iterations. In Iteration 1, six members of the research team coded the first transcript together until consensus was reached. Thereafter, two researchers met to code the remaining transcripts, with a senior research team member spot-checking the assigned codes. For Iterations 2 and 3, the senior research team (and authors of this manuscript) coded transcripts together; differences in coding were resolved through discussion and an adjudicated rating was applied. Given the collective case study approach, results are presented Iteration by Iteration in the results section below.

Results for the design iterations

Iteration 1: *Tree Investigators* socio-technical design for tree/species identification

As reported in Zimmerman et al. (2015), Iteration 1 used a qualitative case study methodology to investigate how our design supported learners to: (a) observe and explain scientifically-relevant characteristics of trees and (b) identify salient differences between evergreen and deciduous trees using both mobile images and specimens at the Arboretum. In Iteration 1, a guide led small groups of families on a tour of 8 trees at the arboretum. They were given the challenge of taking on the role of "tree investigators" to learn how scientists use characteristics of trees as clues for identifying them. Learners were then told they would be identifying a mystery tree at the arboretum, with the help of their iPads. The mobile website provided text and photos for each of the 8 trees toured and was organized around a framework for tree identification and accessible via a QR code (see Fig. 2a). The learning goal was for families to coordinate their on-site observations with scientific explanations about the differences in trees and their characteristics.

Conversational analysis of science talk

Given our interest to support science learning in informal spaces, we employed an analytical framework of conversation elaboration (Leinhardt and Crowley 1998) as a product and process of learning. We used a theoretical-driven approach to code transcripts, line-by-line, for observation and explanation-building talk that was derived from Allen (2002): *perceptual talk* (identification, naming, and describing species); *conceptual talk* (inference, interpretation, and prediction); *connecting talk* (life, knowledge, and inter-species

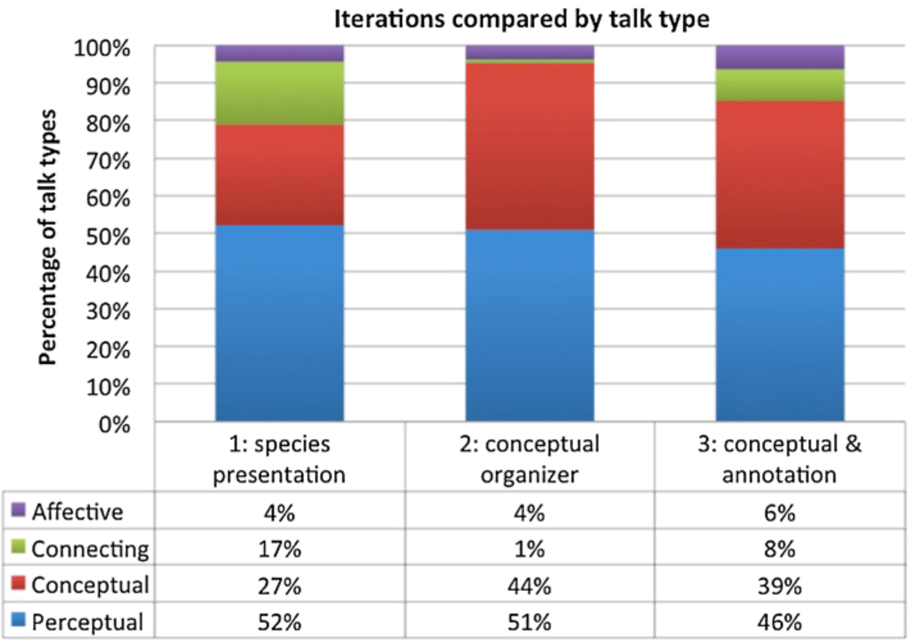

Fig. 4 Patterns of science talk across the 3 design Iterations

connections); and *affect talk* (emotional expressions of positive or negative feelings). Findings related to science talk are presented in Fig. 4.

Figure 4 shows that, in Iteration 1, Tree Investigators supported high proportions of perceptual talk (52 %), compared to conceptual (27 %), connecting (17 %), and affective (4 %) talk. These findings suggest that our program was effective in supporting observational practices such as noticing, naming, and describing relevant characteristics of trees. However, conceptual talk related to interpreting and explaining observations was less apparent.

Case study analysis of a family tour: perceptual and conceptual talk

Although the graph and chart in Fig. 4 shows trends across utterances, these representations do not show the socio-technical dynamics of developing explanations from observations of trees. Thus, one microanalysis episode at the arboretum from a family tour is analyzed. In the excerpt that follows, perceptual talk is marked with [Per], conceptual talk with [Con], references to socio-technical elements of environment are marked with [Env], and guided participation with [GP].

Perceptual talk, combined with connecting talk, is highlighted between two families who worked with a naturalist to make observations about a pine tree. The two boys worked together to use an image of a pinecone from the mobile app and an actual pinecone specimen to learn that a pinecones' shape carries scientifically-relevant information about age and reproductive readiness. In this example, the Naturalist made an overt reference to two other evergreen trees that the youth had seen earlier at the Arboretum, as the youth examined a new tree, the Mugo pine. The youth made observations and also remembered what they previously learned about pinecones:

1. Naturalist: Alright. This [is] also a pine… this is called a Mugo Pine [Env]. We have a White Pine, we have the Limber Pine, and now this is a Mugo Pine [GP] [Env]. Now… what do you notice about the pinecones on this one? [GP] I'm gonna pull one off. ((takes pinecone off of the tree)) [Env].
2. Doug: ((looking at pinecone)) Um, hey those are….
3. Pete: They're round. [Per]
4. Doug: They're short and round. [Per]
5. Doug:… or any kind of round. [Per]
6. Naturalist: Uhhah. And there… and you look at them. They're all wide open, aren't they? What does that mean? [GP]
7. Pete: They're falling out. [Con]

In this excerpt, Pete and Doug were supported by the Naturalist to reflect on what they learned at the White and Limber Pines through coordinating their observations of the specimens and the information on the mobile website. The Naturalist encouraged the boys to apply their existing knowledge to the new tree, the Mugo pine. Consequently, Pete remembered and applied scientific knowledge about the pinecone's appearance to the status of its seed (line 7). This demonstrated a basic appropriation of the scientific knowledge of seeds and cone as they applied tree life cycle knowledge within the practice of scientific observation. The Naturalist used sense-making prompts (line 6) including a reminder to remember what they learned at the other pine trees (line 1), a question prompt to encourage observation, and additional visual support of picking the pinecone off of the tree for closer inspection (line 1) to support the observational inquiry. These acts highlight the role of natural specimens to support science learning, which is enhanced (but not replaced) by computers. After the boys noticed key elements, to move the observation to its scientific significance, the Naturalist used a channeling question prompt (line 6) to further fine-tune the observation to a specific scientifically-relevant aspect of the pinecone. This case shows how observational supports from the mobile technologies and from the naturalist drawing upon environmental objects supported first perceptual talk and then conceptual talk as the learners were able to coordinate their observation into an understanding of tree biology.

Implications for design of Iteration 2

In our first research and design case, our results showed that learners enacted high levels of perceptual talk, suggesting that observational practices were supported, but we saw less conceptual, connecting, and affective talk. Our Iteration 1 mobile materials were designed to primarily support observations (as evidenced through perceptual talk), and our results substantiated this emphasis. We noted that conceptual talk was most prominent during conversations with the naturalist about life cycle concepts and when images or specimens were observed that revealed important visual distinctions with conceptual explanations (e.g., a pine cone that was open and on the ground vs. closed and on the tree); these observations often led to deeper discussions of life cycle concepts. Consequently, our design was revised for Iteration 2 to better expand the conceptual focus to life cycle elements due to families' observed interests. These design changes are discussed in the next section.

Iteration 2: conceptual organizer supporting observations and explanations

Based on Iteration 1 findings, we refined our design for Iteration 2 with three main goals: (a) to focus more intentionally on broader concepts of tree life cycles to promote conceptual talk; (b) to support more learner-directed interactions using mobile technology to support deeper engagement and conceptual application; and (c) to extend the setting to support observing a fuller range of tree life cycles in the environment. We re-designed our mobile resources in Iteration 2 as a mobile app (Fig. 2b) that did not rely on the Internet, since we found that Internet connections were not reliable outdoors in the forested areas. The socio-technical design elements were organized conceptually by the tree's lifecycle in contrast to Iteration 1′s species-centered presentation of content. Learners began with the naturalist leading them to observe an evergreen and deciduous tree in the Arboretum and coordinate this sensory information with the conceptual model of a tree's life cycle on the mobile app. To foster conceptual connections across specimens, we included a graphic organizer (Quintana et al. 2004) of the tree life cycle for the two species (Fig. 2b), which provided a conceptual structure to the content from seed to seedling to sapling to mature tree and then to snag, allowing learners to recognize how each step of the life cycle was connected to other steps as well as the whole life cycle. The naturalist directed learners' attention to the app at each tree and guided them through the material.

Iteration 2 presented learners with the challenge to identify evidence of tree life cycles in the nearby forest, an activity that required application of concepts from one setting to another (Bransford et al. 2000). Learners extended what they experienced in the structured garden environment that used pre-selected trees to a more complex woodland setting with new species and elements not previously encountered. We added a new culminating activity that supported learner-created artifacts with mobile technologies, given that this is a common strategy used to support conceptual integration in classroom, learner-centered frameworks (Baytak and Land 2011; Hannafin et al. 2013; Jonassen and Land 2012; Kafai 2006; Land et al. 2012; Land et al. 2013; Quintana et al. 2004). Participants used the photographic capabilities of the iPad to document various life cycle processes in an old-growth forest. Learners explored the environment in an unstructured way to capture observations of tree life cycles by taking photographs and organizing them into a digital photo collage using the app *InstaCollage*. The naturalist circulated among the families to provide assistance as needed during the photo capture task. Our goals were to support child-directed engagement with science practices in ways that required them to *apply concepts* to a new setting (the forest), as well as *create representations* of their understanding, hence supporting conceptual talk.

Conversational analysis of science talk

As in Iteration 1, we coded transcripts according to Allen's (2002) scheme for science talk. Figure 4 shows that Iteration 2 led to patterns of talk with more balanced proportions of conceptual talk, suggesting that observational and explanation practices were supported, although connecting talk was minimal. We noticed that conceptual talk was most prominent during identification practices in the forest and often took the form of predictions or interpretations about a tree's life cycle phase.

Pretest–posttest knowledge gains

For Iterations 2 and 3, we analyzed an 8-item pretest–posttest assessment on tree life cycle knowledge (open-ended format) using paired t-tests to ascertain if we supported knowledge

Table 2 Iterations 2 and 3 paired-samples *t* test of the pretest and posttest scores from the children

	Mean	N	SD	*t*
Iteration 2				
Pretest scores	4.5	10	2.6352	8.647***
Posttest scores	14.3	10	2.7101	
Iteration 3				
Pretest scores	4.9	13	2.6287	11.502***
Posttest scores	11.4	13	2.6312	

*** $p < .001$

acquisition. The participating children were given an 8-item assessment of life cycle knowledge, provided in an open-ended response format, both before and immediately following the learning activities. The assessment investigated knowledge acquisition about tree life cycles and included questions like "What are the seeds of an oak tree called?" and "What holds the seeds of a pine tree?" For these types of questions, one point was assigned for each correct answer. Other questions asked participants to list as many characteristics as they could about tree life cycles: "List the stages of the life cycle for trees" and "What are some of the differences between sapling and mature trees? List all the differences you can think of." For these questions, one point was given for each correct characteristic or stage listed. The points for each item were summed to form a score for the knowledge assessment test, and all students were measured individually. The two researchers scored each test together to ensure agreement on the score. Table 2 reports a significant increase in mean scores ($t = -8.647$, $p < 0.001$), and Cohen's effect size value ($d = 3.67$) suggests a very high practical significance.

Video analyses of identification practices in the forest

We analyzed video of (a) the processes learners used to identify life cycle stages in the forest and (b) elicitation interviews with the children about their photo collage artifacts. The process of creating the photo collage was a collaborative endeavor between children, adults, and naturalist. The families applied what they had learned during the mobile learning activities to identify specimens in the old growth forest that were exemplars of the five life cycle stages. The families shared their life cycle observations with each other and other families. For example, a mother and daughter who found an oak seedling offered the seedling as an example to include on others' photo collages.

However, the identification process in the forest was challenging for the children, as evidenced by frequent consultations with the naturalist and parents for identifying and photographing species. The complex forest setting meant observing species that they had not encountered during the structured learning experience in the Arboretum. The distinction between sapling and seedling was a difficult concept for children. Some children simply (but correctly) concluded that a sapling was an "older" tree than a seedling, while others could not recall any criteria for distinguishing seedlings from saplings. We noted that this seedling/sapling distinction was also a challenge on the knowledge assessment.

In some instances, children could correctly identify a tree in its life cycle in the forest, but the criteria provided for its selection was irrelevant. This is shown in the following excerpt with Emory (age 9) and Rosa (mother):

1. Rosa: what have you found already?
2. Emory: I found a sapling [pauses]

3. Rosa: What about a mature tree?
4. Emory: I'm trying to find one right now. Like right there.
5. Rosa: You think that is a mature tree?
6. Emory: Cause, like that one with the red leaves on it. Because that has red leaves on it and that usually means it is mature. Or some of those yellow trees over there.

Although her identification of a mature tree was accurate (line 4), Emory attended to characteristics that were relevant for seasonal cycles (line 6), but not for identifying a tree's life cycle, meaning she did not accurately *explain* the evidence for her identification. Similarly, other children, when asked to explain their photo collage selections, relied on simple criteria such as "the tree is mature because it is big", and or were unable to apply life cycle vocabulary. Pairing criteria for conceptually distinguishing trees and identifying them in the forest was challenging for most learners observed.

Although a few vocabulary words proved to be difficult for some children to appropriate, the learners consistently explained the ideas of life cycle conceptually during their debriefing interview—in general terms such as the seed grew to become a grown tree capable of growing seeds and trees eventually died. All the children were able to take photographs and create a collage with assistance from adults and each other. In fact, two learners took over 100 additional photographs during their visit, yet both still engaged in learning tree lifecycle concepts while taking these photographs. These observations point to the potential role of learner agency and child-centered interactions using mobile technologies.

Implications for design of Iteration 3

We identified two main findings with implications for our next iteration of design and research. First, we saw a more distributed pattern of perceptual and conceptual talk, suggesting that elements of our design supported conceptual talk in the form of predictions or interpretations. Our observations revealed that conceptual talk was most often preceded (72 % of the time) by the naturalist making connections between the mobile app content and identification of species in the environment. We also saw learners engage in conceptual talk during the photo-capture task, but as presented in our qualitative findings, this talk sometimes reflected simple claims or interpretations, without evidence for their explanations. Consequently, we made the following changes to our design for Iteration 3: (a) support better connections between in-field observations and conceptual explanations (Sung et al. 2014) by building a customized photo capture tool and (b) revise app material to be clearer about the evidence for distinguishing between seedling and sapling.

Iteration 3: conceptual organizer with annotations to support identification practices

The third research and design case, Iteration 3, used a similar set of mobile materials and procedures as Iteration 2, but the setting changed to a summer camp at an environmental center. This new setting enabled us to extend our design strategies to peer learning interactions. As in Iteration 2, the naturalist led children on a structured tour of two mature trees: an oak and a pine tree, but in this new forest setting, the naturalist was often able to point out nearby trees on the trail at other stages of the life cycle (e.g., saplings). Unique to Iteration 3, children used a customized tool that was embedded into our mobile app for managing the complexity of capturing, organizing, and annotating photographs around tree life cycle concepts at the time of identification. This tool embedded pre-identified criteria for distinguishing life cycle stages that can be applied quickly in the forest as "check boxes" (Fig. 3a); Criteria for each life cycle stage were visible to learners as they took photos, which were "checked off" as they saw them. The checked items annotated the learners' photos, which were compiled together into a collage that mirrored the conceptual life cycle model (Fig. 3b). The naturalist circulated among the children to provide assistance as needed during the photo capture task.

A brief summary of the findings is presented below. Similar to Iteration 2, Table 2 Row 6 reports significant increases in mean scores ($t = 11.5022$, $p < 0.001$) in Iteration 3, with very high effect size ($d = 2.46$). Likewise, Iteration 3 produced a pattern of science talk with high levels of perceptual and conceptual talk, but few links to connecting talk and affective talk (Fig. 4). Regarding identification practices of tree life cycles, the photo capture/annotation tool assisted learners in articulating criteria for their selection at the point of photo capture, as shown by the following excerpt with two children:

1. Migel: We are doing seedling now.
2. Beth: wait, you don't know what we have to look for, we have to look for a root, a stem and at least one leaf.
3. ((Migel holds tablet))
4. Beth: ((over his shoulder)) It has to have a root, a stem and at least one leaf.

During photo elicitation interviews, these two peers and their third partner elaborated evidence for their artifacts:

1. Migel: And we knew this one was a, um, a sssssseedling, because we knew that the tree that it was smaller, than a sapling but bigger than a pine cone.
2. Researcher: So what were the criteria that you looked for when deciding that was a seedling?
3. Migel: Well it was less than 2 ft. It had less leaves than a sapling.
4. Researcher: Okay, so let's move on to your…
5. Beth: The sapling is bigger than the seedling but smaller than the mature tree. And also taller than two feet which is how-
6. Researcher: Any other criteria that you use when you were trying to decide if it was a sapling?
7. Migel: We, really thought about it.
8. Caroline: that you could put your hands around it [the trunk].

These kinds of conversations, while both identifying species in the forest and later explaining them, were present across most participants, reflecting more integrated connections between observations, explanations, and the environmental setting.

Influence of the socio-technical system on science talk

A driving perspective of our research was to support children's ability to make observations (as measured through perceptual talk) and to think conceptually about scientific phenomena (as measured through conceptual talk). Our study was designed as a qualitative design-based research study with three related cases, as opposed to a controlled, multi-study quasi-experimental or experimental design with three conditions; thus, comparisons across Iterations need to be treated as trends from patterns emerging from the learners' talk. Iteration 3 represented our most refined design to achieve our intended goals; thus, in order to more deeply understand what aspects of our socio-technical system influenced perceptual, conceptual, connecting and affective science talk, we analyzed all the coded talk types for Iteration 3 with other talk adjacent to those coded to identify patterns.

As expected with our socio-technical design, conversations preceding different types of science talk exemplified more than one dimension of our design, for example, the naturalist [guided participation] pointing out the connection between an image on the app [mobile technology] and a real tree specimen [environment]. For Iteration 3, we found that perceptual talk and conceptual talk were preceded most commonly by interactions where the naturalist directed learners to make connections between the app material and the environment. Thirty-six percent (36 %) of perceptual talk was preceded by naturalist-app-environment interactions, and 41 % of conceptual talk was preceded by this socio-technical configuration. However, learner-initiated talk that coordinated the app material, the environment, and other people preceded perceptual talk 30 % of the time and conceptual talk 34 % of the time. Connecting talk was initiated predominantly by the naturalist directing learners to connect app material and the environment (77 %); we posit that this is because connecting talk often links one human's experience to another's and therefore, the naturalist was more influential in sparking the connecting talk than other designed supports. Affective talk showed the reverse trend with 64 % of the talk being initiated by learners engaging conversations with the naturalist about the environment or with other learners about the app material applied to the environment. This suggests that science-related interest more often emanates from learner-initiated interactions with the environment. Taken as a whole, these findings suggest that certain configurations of the socio-technical system supported different forms of science talk and that these configurations were not solely initiated by the guide or technology; rather, epistemic agency was also evidenced from the learners as they participated within the socio-technical system.

These general trends also were observed in Iteration 2 for perceptual, connecting, and affective talk; however, conceptual talk showed a different relative pattern with 72 % of conceptual talk being preceded by prompts from the naturalist to make connections between the app material and the environment (vs. 11 % initiated by learners). We posit that this shift in pattern from Iteration 2 to 3 could possibly be attributed to higher counts of conceptual talk, and by extension epistemic agency, evidenced during the photo-annotation activity. We speculate that this is due in part to the photo capture/annotation support provided for learners to engage and justify identification practices. We suggest that the photo annotation tool served as a scaffold to "simplify elements of the task so they are within reach of learners" (p.181) and to support "learning by doing in context" (p. 184) (Reiser and Tabak 2014), which made conceptual conversations possible. We also recognize the related influence of the social configuration of learners working collaboratively as peers, perhaps enabling more conceptual talk resulting from the need to substantiate evidence to each other, as they engaged in identification practices. These findings warrant investigation in future work.

Discussion

As indicated by our *Tree Investigators* findings for Iterations 1, 2, and 3, mobile devices delivered science content, supported families' scientific talk, provided access to knowledge not always visible in a setting, and created artifacts on-the-go with mobile apps. Across the Iterations of our qualitative DBR research, mobile devices enabled engagement with trees, not just the devices. Researchers have expressed concern about "heads-down" interactions with technologies (e.g., Hsi 2003), where learners spend time engaged with the screen, rather than the scientific phenomenon. We found that images, text, and photo capture tools—when supported by a naturalist in the outdoors— encouraged visitors to engage with the natural setting around them. The socio-technical elements (Pea 1993) that guided our design worked in concert to enable learners to connect science knowledge in authentic natural settings.

Fostering talk related to conceptual and connecting elaboration, which is aligned with scientific practices of explanation, was the most challenging. Our findings demonstrated increases in the proportion of conceptual talk with more predictive and interpretive talk by adjusting the task structure, along with providing technology scaffolds to assist learners (Reiser and Tabak 2014); this result shows promise as a design consideration for other mobile learning projects using a distributed, socio-technical system approach. In order to connect their onsite observations with scientific concepts and apply higher levels of explanation, learners needed a combination of a naturalist, mobile-delivered content material, technology tools for collecting and annotating evidence, and scaffolds for noticing relevant features in a complex environment. This finding points to the utility of distributed scaffolding strategies (Tabak 2004) to support deeper conceptual talk within mobile designs.

Future work should investigate different configurations of the socio-technical system to scaffold knowledge building activities of families, especially scaffolds for parents who could potentially serve as guides for their children's explorations. Research shows that families can support each other's knowledge-building efforts (Palmquist and Crowley 2007; Zimmerman et al. 2013; Zimmerman et al. 2010b), and parents can be scaffolded to ask guiding questions to support their child's science learning in museums (Tscholl and Lindgren 2014) and outdoor spaces (Eberbach 2009). Future work on mobile computing for ILIs should also examine conditions that lead to more science talk that connects to everyday life, by enhancing the proposition of connecting talk (Allen 2002), which was only minimally observed in our study.

Implications for Design and Research

Our research iteratively investigated the synergistic design elements of a socio-technical system for mobile learning outdoors. Our findings point to several implications for design and future research, which we discuss by returning to, and expanding upon, our overarching theoretical and design conjectures.

Design conjecture 1: support learners to make scientific observations outdoors

This conjecture points to the support needed for learners to engage in science-specific observational practices in the outdoors (Eberbach and Crowley 2009; Zimmerman et al. 2013). In our design, these supports came from both the naturalist and mobile technology. Mobile resources helped to channel the learners' attention (Pea 2004) to specific features of the environment that highlight disciplinary concepts (Quintana et al. 2004) when guided by the naturalist who could help learners make connections between images or text and the environment. The naturalist-technology-environment interaction supported learners to engage in perceptual and conceptual talk, as learners were directed to observe critical features in the environment that might otherwise escape their attention. Although initially designed to support observations and perceptual talk, we found that digital images, when paired together as contrasts, could also lead to conceptual talk when guided by the naturalist. Bransford et al. 2000 note that "appropriately arranged contrasts" (p. 60) can help learners notice new observations they would not see otherwise, but they can also support conceptual learning. In our work, we saw this most readily with the images and specimens of open versus closed pine cones, when learners' observations led to further questions which in turn led to conceptual talk around life cycle concepts. Moving forward, we could see how contrasting seasonal/non-seasonal photos could serve a similar dual role in supporting talk: can contrastive images be designed to serve both conceptual and perceptual functions? Likewise, contrasting images of similar features across multiple specimens might produce a comparable dual talk effect, such as highlighting how seeds that produce a maple tree reveal fuller application of disciplinary concepts beyond what could be explored within one or two types of trees. Future research and design efforts could explore ways to use paired contrasts to point learners to deeper conceptual conversations in outdoor learning settings.

Design conjecture 2: use child-centered designs for mobile learning

Underlying our design is an assumption that technologies, pedagogy, and guided participation strategies need to work together synergistically (Reiser and Tabak 2014; Tabak 2004) to connect to learner's existing knowledge, progressively build on it through interaction, and encourage learner epistemic agency (Jonassen and Land 2012; Zimmerman et al. 2010b). This design guideline is meant to allow all participants—regardless of age and reading ability—to engage as capable knowledge-building agents of tree life cycle concepts.

As reported in our findings, we saw evidence that our design supported child-centered interactions in multiple ways. First, we observed that children were engaged in productively using mobile technology, often jointly with others. We presented multiple forms of evidence across the three iterations: children's interest in taking several ecologically-focused photos of specimens outdoors, seeking opportunities to hold and read from the iPads, and using the iPads as we intended to engage in science talk. Second, we reported that in Iteration 3, learners initiated perceptual and conceptual talk about trees almost as frequently as the naturalist initiated such talk. Such learner-initiated talk has been shown to be connected to family sensemaking in science centers (Zimmerman et al. 2010b) as well as in our prior work with mobile computers (Zimmerman et al. 2015). In the present study, learner-initiated talk took place most commonly during the photo documentation activity, which was supported through a synergistic and distributed support tool (Pea 2004; Reiser and Tabak 2014) in the form of an embedded checklist for documenting life cycle photographic evidence. The checklist functioned in multiple ways: (a) provided a reminder of the prior supports at the point of the children's decision-making; (b) provided a means for informal check-in of the children's understanding for the naturalist; and (c) was easy to deploy and use in the outdoors during walking tasks, allowing for sensory interaction with trees on the trails. We posit that these findings related to leaner-centered conceptual talk are evidence that we achieved our child-centered pedagogy that is rooted in assumptions of learner-centered, open learning environments (Hannafin and Land 1997; Hannafin et al. 1999; Hannafin et al. 2013; Jonassen and Land 2012; Land et al. 2012).

Design conjecture 3: use conceptual models (Quintana et al. 2004) across activities versus discrete factual knowledge tied to singular objects

This design conjecture is intended to advance an informal, mobile learning pedagogy away from strategies that tie content to specific objects and towards broader ecological concepts across objects within a setting. Given our theoretical perspective (Pea 1993) and corresponding research design, we did not isolate the influence of our conceptual organizer alone as a variable to support conceptual talk; however, we did find evidence that engaging learners in exploring conceptual cycles in the outdoors, with the help of technology and a guide, enabled learners to engage in high levels of conceptual science talk. We also saw evidence of learners effectively applying concepts learned about one species of tree to another and doing so in a complex, authentic outdoor setting. We speculate that the conceptual model, which organized both the sequence of learners' activities and the flow of content material, played an important role in helping us realize the socio-technical system that focused on applying and appropriating science concepts. The other influence on conceptual talk worthy of further discussion was the contrastive information that led to conceptual talk by "problematizing" the observational data (Reiser and Tabak 2014). As discussed in Design Conjecture 1, the contrasting images brought forth a need, or discrepancy, for learners to develop new and better explanations. Future research should investigate these two supports for conceptual thinking through scaffolding strategies that can be faded over time that assist learners to apply concepts within and across settings.

Design conjecture 4: scaffold complex disciplinary practices in natural settings

We incorporated into our design supports that enabled learners to participate in complex practices of observation and identification that are challenging without such support (Eberbach 2009; Pea 2004). Iteration 2 found that learners' efforts at identification in the forest were limited without observational support at the time of identification. Given that informal programs like ours might employ only one guide for a small group of people, we investigated in Iteration 3 whether part of this expert guidance could be offloaded to the technology to support both identification practices in real time and connecting science explanations to learners' in-field observations (Sung et al. 2014). Our photo capture and annotation tool shows promise as a means to provide this support, as evidenced by our observations of learners engaging identification practices in the field as well as analyses of learner artifacts and talk that pointed to learner-initiated conceptual talk. The photo artifacts were collaboratively created, often with assistance of peers and adults, and consequently do not serve a summative assessment role. However, the photo artifacts served an important role in mediating learner agency, communicating what is known to the guide/teacher, and as a photo elicitation method supporting articulation and reflection (Land et al. 2009).

In conclusion, the contribution of our design-based research study is in informing technologically-enhanced designs for learning outside of school. This study suggests that pedagogical efforts that utilize mobile devices to support informal science education can enhance families' and children's learning experiences in the outdoors. We advocate for additional research, based on the results from our studies, on how mobile technologies can be used in out-of-school settings to support learner-centered observation and identification practices.

Acknowledgments This research is supported by Penn State Center for Online Innovation in Learning and Penn State Education Technology Services (Teaching and Learning with Technology Unit). We acknowledge the contributions of our Augmented and Mobile Learning Research Group (http://sites.psu.edu/augmentedlearning/): Lucy R. McClain, Michael R. Mohney, Gi Woong Choi, Brian J. Seely, Jaclyn Dudek, and YongJu Jung.

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