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Sparking interest: A design framework for mobile technologies to promote children's interest in nature

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ABSTRACT

Can a mobile app engage children in explorations of the natural world and promote their interest in nature? Drawing on theory related to interest development and research on mobile learning technologies, we derived a set of four design principles to support the development of children's personal interest in nature. We co-designed with 7 children ages 7–12 a set of interest-centered design strategies to implement each of the following principles: (1) personal relevance, (2) focused attention, (3) social interactions, and (4) opportunities for continued engagement. We applied these strategies to design *NatureCollections*, a mobile application that allows children to build, curate, and share nature photo collections. We conducted an in-situ case study with 18 children ages 7–11 years who used the NatureCollections app to take pictures of their natural surroundings. Qualitative indicators suggest NatureCollections succeeded in directing children's attention to and promoting close observation of the natural elements in their surroundings, and prompted playful, nature-related conversations with peers and parents.

1. Introduction

Globally, children are spending less time outdoors than the generations before them [1,2]. In 2016, U.S. children spent 50% less time than their parents playing in nature [2–4]. At the same time, a 2015 U.S. survey showed that children ages 7–13 spent approximately six hours per day using screen media entertainment, which excludes screen time spent for homework and while at school [5]. Spending less time in nature has negative implications for children's developing attitudes towards and interest in nature [6,7]. Indeed, a 2011 poll from The Nature Conservancy found that 49% of U.S. children reported a lack of interest in spending time in nature [8].

This state of affairs is problematic on both an individual and a societal level. On an individual level, a failure to develop an interest in nature may negatively affect children's nature-related science learning. Personal interest – characterized by concentrated attention, positive feelings, and a likelihood to re-engage with the same topic [9] – is an important dimension of learning, including science learning [9,10]. On a societal level, prior research has found a connection between individuals' positive perceptions of childhood experiences in nature and their positive attitudes and actions towards the environment as adults [11,12]. Reducing habitat loss, a major driver of biodiversity loss, depends on these positive attitudes and actions [13,14].

Whether fairly or not, networked technologies are often seen as the source of our current problems [15,16]. At the same time, these technologies are increasingly used to design solutions to problems such as sleep deprivation [17], empathy decline [18], and decreased attention [19]. With respect to interest development, prior work has demonstrated that technological infrastructures can support interest-driven engagement and learning by allowing students to tailor activities to their personal interests and extend activities in unanticipated ways [20].

Work conducted in the field of mobile learning technologies leverages the affordances of mobile and networked technologies to engage children in outdoor settings . Although this work has yielded promising results with respect to promoting children's exploration of, and learning about, nature [21–26], it has not placed interest development at the center of design-based investigations. In fact, a persistent challenge surfaced by this work relates to children's tendencies to engage with their handheld devices rather than with their surroundings when they are in an outdoor setting or in front of a museum exhibit [27,28]. This is a particular problem for interest development, which requires focused attention to trigger and sustain it [9].

In the current work, we explore the potential for a mobile application to spark children's interest in nature. This work is motivated by prior research showing that the development of a sustained personal interest in a topic begins with an externally triggered situational interest [9]. Whereas a personal interest is an enduring

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predisposition to re-engage in a particular content, a situational interest arises in the moment and may be relatively fleeting if not supported beyond that moment [9,29]. We ask the following research questions: ***RQ1****: What are the design considerations to spark children's interest development in their natural surroundings?;* and ***RQ2:*** *In what ways can embodying these design considerations in the features of the NatureCollections app contribute to triggering children's situational interest in nature?*

Drawing on Hidi and Renninger's model of interest development [9] and prior research on mobile learning technologies [25,30,31], we derived a set of four design principles to guide the design of technologically-enhanced interactions in natural settings that support children's interest development in nature. We then conducted several co-design sessions with children ages 7–12 to derive design strategies to implement our theoretically derived design principles. We embodied these strategies in the design of *NatureCollections*, a mobile application that encourages children ages 7–12 to explore nature through gamified challenges to create, curate, and share nature photo collections.

We conducted an in-situ evaluative case study with 18 children ages 7–11 in an outdoor setting, using the NatureCollections app. Our findings suggest that using NatureCollections can trigger a situational interest by: (1) encouraging children's directed attention to and close observation of the natural elements in their surroundings, and (2) promoting playful interactions with peers and parents around nature.

The main contributions of this work are: (1) an interest-centered design framework for mobile technologies to promote children's interest development in a topic, and (2) empirical insights from a case study that applied the interest-centered design framework to design, develop, and evaluate the NatureCollections app.

2. Related work

2.1. The connection between interest and learning

Interest is central to learning in any domain, including science [9,20,29,32]. Learners are more likely to focus on, commit to, and persist in a learning activity when they care about and find enjoyment in it — in other words, when they are *interested* in the activity. Interest-driven learning is characterized by self-motivated engagement in a topic over the short- or long-term [20,29]. A learner who engages in interest-driven learning feels personally connected to the topic and is able to make connections to prior knowledge and experiences [9,32]. Much of the research on interest-driven learning centers on informal learning contexts, such as after-school programs [10,33–35], museums [36], and science centers [37]. Compared to formal classroom settings, which often follow a predetermined structured curriculum, informal learning contexts afford greater freedom for learners to pursue their interests in a self-directed manner [20]. Though self-directed, interest-driven learning is also highly social [20,32].

We focus on interest development in nature-based informal settings as a central dimension of support for interest-driven learning about nature. The unstructured quality of natural settings lends itself to engaging learners in self-directed activities guided by their personal curiosities and inclinations. However, survey data suggests that when considering children's diminishing time in nature, a lack of interest is an important component [8]. Therefore, there is a need for interventions that promote children's interest development in nature, both to support nature-based science learning and to encourage children to become responsible stewards of the environment [11,12,14,38].

2.2. A theoretical model of interest development

The design of NatureCollections is theoretically informed by Hidi and Renninger's four-phase model of interest development [9]. The model highlights the importance of promoting focused attention and positive affect, and describes how an externally triggered situational interest can develop into a sustained personal interest through repeated engagement in personally relevant and socially supported experiences. We argue that Hidi and Renninger's model provides: (1) guidance for how to design technologies to support interest development, and (2) focus for how to observe children's development of interest-driven participation.

Hidi and Renninger define personal interest as a psychological state characterized by focused attention and positive feelings towards a particular content, as well as a predisposition to re-engage with the content repeatedly [9]. Interest differs from related constructs such as motivation, in that engagement is accompanied by a positive emotion (affective component), as well as perceptual and representational activities associated with engagement (cognitive component). The four-phase model of interest development describes how an internally driven personal interest emerges from an initial external stimulus. Although the model was developed with academic interest in mind, prior work has used it to study interest development in informal settings [38].

Each of the four phases in the model is distinct and sequential in its order of development and progress. In the first stage, a *triggered situational interest* results from the introduction of an environmental stimulus that is personally relevant, intense, or otherwise unexpected. This external stimulus sparks positive feelings and focused attention, which form the basis of a *maintained situational interest* when they are sustained over an extended period of time through meaningful interactions. Both a triggered and a maintained situational interest are externally supported by other people and/or structured tasks. Without such external support, an interest may become dormant or disappear altogether. During the course of repeated engagement with a particular content, an *emerging individual interest* develops as an individual starts to value the content based on prior experiences engaging with it. An emerging individual interest requires some external support in the form of encouragement from others and an environment that provides opportunities for re-engagement. Lastly, a *well-developed individual interest* results when an individual has formed an enduring predisposition towards a topic that is marked by deep positive feelings and accumulated knowledge.

Although each phase of Hidi and Renninger's model is distinct, they share common characteristics that contribute to and support interest development. These characteristics include *focused attention* on *personally relevant content*, *supportive social interactions*, and *opportunities for continued engagement*. We drew on these crosscutting characteristics to derive the four design principles that form the foundation of our interest-centered design framework. Because the characteristics appear in each phase of Hidi and Renninger's model, our interest-centered design framework – and, by extension, the NatureCollections app that we designed using the framework – addresses all four phases of the interest development model. In our initial evaluation of the NatureCollections app, we focused specifically on the first phase of interest development: a triggered situational interest. This decision was guided in part by the brief nature of our field test, as well as the fact that a triggered situational interest is a necessary precursor to further interest development.

2.3. Designing mobile technologies for nature exploration

Our work is also informed by prior research that leverages mobile technologies to engage children in nature-based learning experiences. This work aims to support learners in informal settings by using location awareness capabilities, social features, built-in data collection functions, and just-in-time prompts.

2.3.1. Place-based and context-aware technologies

Projects that support nature explorations, such as *EcoMOBILE* [24], *iBeacons* [39], *GeoTagger* [40] and *Tree Investigators* [26], harness the location awareness capabilities of mobile and augmented reality (AR) devices to deliver content tailored to a particular place in order to engage learners within their physical settings [24,26, 39,40]. In several of these projects, mobile devices augment real-world locations with an overlay of virtual information and narratives to support scientific observations [24,26,39]. Researchers on the EcoMOBILE project reported that AR design elements enhanced learners' engagement in their scientific inquiry about a pond ecosystem by providing detailed views such as closeups of microscopic organisms that would not be possible otherwise [24]. Similarly, iBeacons pushed content and learning activities based on the proximate location of the arboretum visitor to the relevant nature element or place [39]. Tree Investigators, comparably, supported learning about tree species diversity by using an overlay of images and text to amplify learners' observations [26]. Researchers reported that AR enhanced learners' observations and increased their interactions with peers during a field trip [22,24, 26,41]. Projects such as these build off of earlier efforts aimed at leveraging mobile technologies to support outdoor exploration, e.g., [42].

2.3.2. Social media tools for science inquiry

Researchers have also used social media tools and features, such as *ScienceKit* and *Science Everywhere*, to support scientific inquiry in informal community-based learning settings [31,43]. Researchers found that appropriating social media facilitated social scaffolding and personal expression along with supporting children's learning about science in their everyday lives [31,43].

2.3.3. Balancing supports and learner autonomy

With many projects related to mobile learning technologies, researchers seek to strike a balance between encouraging children's free choice exploration – a key component of interest-driven engagement [20] – and providing external support [26,36,37,44,45]. To create engaging learning experiences and guided exploration, researchers have used the built-in data collection capabilities on mobile devices to enable learners to capture, annotate and reflect on the data they collect [30,44,46,47]. For instance, *Zydeco* encouraged learners to take photographs, produce audio recordings, and annotate data collection in museums to bring back to their classroom.

External support can be in the form of just-in-time information and prompts to support and direct learners' scientific inquiry. For instance, the *Ambient Wood* project pushes content such as pre-recorded sounds of insects scuttling into the devices, enabling the students to discover elements in their surroundings that otherwise might go unnoticed [47]. Likewise, iBeacons detects proximate devices to push relevant information and activities [39].

The balance between external support and free choice exploration can be difficult to achieve. Researchers on the Zydeco project found that introducing too much structure limited learner autonomy [46], which has negative implications for promoting self-motivated, interest-driven learning [20]. Externally imposed content may also cause distractions for learners. Across some of the projects discussed, educators reported a recurrent concern that learners were looking at screens and interacting with their mobile devices instead of focused on their surroundings [24,26–28,48]. The excessive interactions with the device screens represent a challenge to promoting focused attention in nature.

3. An interest-centered design framework to promote children's personal interest in nature

We used Hidi and Renninger's model [9] to derive a set of four design principles that reflect core dimensions of interest development. Through a series of sessions with an intergenerational co-design team of children (ages 7–12) and adults, we identified specific design strategies to implement each theoretically derived design principle (Table 1). These strategies are intended to guide the design of mobile technologies that promote children's interest-driven nature exploration. We describe the four design principles, followed by our process of using co-design with children to identify design strategies to implement each principle.

3.1. Design principles to support interest development

We derived the following four design principles by extracting core dimensions of interest development that appear in all four phases of Hidi and Renninger's model [9] and connect to insights from prior research on mobile learning technologies e.g., [25,30, 31,44]. For instance, Hidi and Renninger's model emphasizes social support in all four phases of interest development, from a triggered situation interest to a well-developed individual interest. Prior research has also found social support to be an important factor in designing learning technologies [33,42,43]. We took a similar approach for each major dimension of interest development, considering it in light of specific successes and challenges identified in prior research.

Design Principle 1: Engage children in personally relevant activities. Personally relevant activities draw on children's existing interests to foster positive feelings and engagement with new topics. A situational interest is triggered by external stimuli, which introduce personally relevant or surprising information [9]. Continuing to support meaningful personal experiences maintains interest over time, helping to turn a triggered situational interest into a more sustained individual interest [9,49].

Design Principle 2: Support children's focused attention on their surroundings. This principle emphasizes the importance of providing opportunities for prolonged, focused engagement with a topic. Typically supported by external stimuli, prolonged engagement helps to maintain an otherwise fleeting triggered interest over time [9].

Design Principle 3: Encourage children to engage in social interactions. Social interactions and relatedness represent a key mechanism for sparking and sustaining interest in a particular topic, helping to transform it from a situational to an individual interest [9,50]. Participatory social interactions, especially with peers, can be highly engaging, and can lead children to deepen their interest [9,50] and to learn more about a topic [32].

Design Principle 4: Provide opportunities for continued engagement. This principle helps transform a triggered situational interest into an emerging individual interest. Emerging individual interests require some external support for opportunities to re-engage with a topic [9].

3.2. Co-designing with children

We employed the Cooperative Inquiry method [51] to distill a set of design strategies to implement our theoretically derived design principles and to gather design ideas for the features of the NatureCollections app. Cooperative Inquiry is a method of participatory design in which children and adults equally and equitably partner together to ideate, design, test, and evaluate new child-focused technologies [51,52]. We conducted three 90-minute co-design sessions with KidsTeam over 3 months. Each design session consisted of activities selected to best explore and derive design strategies for the theory based design principles. In each session, we focused on one of the following three design principles: *(1) Personal Relevance (2) Focused Attention,* and *(3) Social Interactions.* In all three design sessions, we explored ways to support Design Principle 4: *Opportunities for Continued Engagement*.

Table 1
Interest-centered design principles and strategies to guide the design of mobile technologies that support interest development in nature.

Interest-centered design principles	Design strategies to support personal interest development	NatureCollections feature examples
1. Engage children in personally relevant activities	1.1 Support children's pre-existing personal interests through customizable activities	Onboarding Screens, My Collections
	1.2 Provide opportunities to extend activities by unlocking new content	Onboarding Screens, My Collections
	1.3 Create a personalized user interface	Onboarding Screens
2. Support children's focused attention on their surroundings	2.1 Draw attention to specific elements in the child's physical surroundings	"Add Details," Photo Classification
	2.2 Encourage self-directed, sensory interactions with natural elements	"Add Details," Photo Classification
3. Encourage children to engage in social interactions	3.1 Connect users with each other and provide conversational prompts around topics of interest	My Friends, "Add Details," Challenges
	3.2 Create activities that involve two or more users to complete	Challenges, My Friends
4. Provide opportunities for continued engagement	4.1 Display children's accumulated progress over time	Tracking Progress, Challenges, Collections
	4.2 Promote app engagement across settings	Tracking Progress

3.3. Participants and context for co-design

KidsTeam consists of both children participants and adult researchers cooperating around design activities. KidsTeam includes seven children ages 7–12 years [$M = 9.3$, $SD = 1.6$] (three girls and four boys). We recruited children that were ethnically and socioeconomically diverse in an urban area (two Asian/White, one Asian/Black, one Native/Asian, one Hispanic, one Asian, and one White). The adults were a mix of professors and graduate and undergraduate researchers. Each KidsTeam session follows the same format. *Snack time (∼15 min)* allows children and adults to socialize and play together. In *circle time (∼15 min)*, we present a question of the day to prime children and adults for the instructions and focus of the session. During *design time (∼45 min)*, children and adults divide into smaller groups and co-design artifacts together to create new designs and ideas or engage in design related activities. Finally, *discussion time (∼15–20 min)* , gives children and adults a chance to reflect and present to the full group and to synthesize the common design themes.

3.4. Data collection and analysis

We video-recorded and photographed each design session. We used a single video camera that recorded group dynamics during co-design activities and researcher-facilitated design discussions, rotating it periodically to sample as much of the small group activity as possible. All researchers took field notes and produced analytic memos immediately following each session. We began our analysis by examining the initial design themes generated during discussion time at the end of each session. The children in each design group shared their ideas and design artifacts, and a researcher distilled and documented cross-cutting themes on a whiteboard. Displaying the themes served as a validity check, as children and researchers could react to and build on the themes. Based on this initial analysis, we re-examined researchers' memos and collaboratively reviewed the artifacts produced by the children to revise and refine the dominant themes in light of our four design principles. This allowed us to identify design strategies that could be used to implement each design principle. To validate these design strategies, the first author reviewed the video data and field notes from each session to identify "critical events" representing each theme [53]. The research team reviewed these events alongside our analytic memos, discussing their relationship to each design strategy. The following sections discuss each co-design session and the design strategies that emerged from them. We use pseudonyms to protect children's privacy.

3.5. Interest-centered design strategies

3.5.1. Design strategies for principle 1: Personal relevance

In the first co-design session (August 2016), we explored ways to incorporate personalization around interest-driven explorations. First, KidsTeam children participated in a 15-minute outdoor activity, where they were given a smartphone with a camera to use while exploring an outdoor garden. Second, based on our observations of the outdoor activity, we asked small group teams to reflect and brainstorm ideas for mobile app features that support nature exploration. Each design group used Bag of Stuff [51] (large bags filled with craft materials) to create low-fidelity prototypes. The design groups then used the Big Paper [54] (large Easel sized paper for collaborative sketching) to draw design ideas.

(1.1) Support children's pre-existing personal interests through customizable activities

We recommend that designs support children's pre-existing personal interests through a variety of customizable activities. Designs should also be flexible enough to adapt to new emerging topics of interest. We observed that KidsTeam children were drawn to curating and customizing photo collections of nature that aligned with topics they found personally compelling. For example, during the co-design session, several children proposed the app elicit what they like and provide prompts to point to those interests, as Adam [boy, age 8, Hispanic] articulated as "*Take a photo of something you like*".

(1.2) Provide opportunities to extend activities by unlocking new content

We recommend that designs reward children's engagement with a topic by unlocking new activities or by highlighting similar activities. During the co-design session, children were inspired to explore new topics and nature experiences by collecting new photos taken from different locations, as Pamela [girl, age 9, Asian/White] shared: "*The more photos you take the more your dragon (the guiding character) grows … and when you take rare photos then you unlock a new location to explore.*"

(1.3) Create a personalized user interface

We recommend user interfaces attempt to guide the child's app and activity experiences. Designing personalized prompts and/or compelling characters may enhance children's feelings of personal connection to the content presented. We observed all children in the co-design session propose a character that shared their nature journey and provided contextual prompts to help build their nature photo collections. India [girl, age 8, Asian/Black] explained: "*Flowly, a golden flower with a smile, will guide through taking photos…If I take a photo, Flowly will grow…When you take more photos and draw nature elements you earn rewards…*"

3.5.2. Design strategies for principle 2: Focused attention

In the second co-design session (October 2016), we considered ways to direct children's attention to their natural surroundings. We asked the KidsTeam groups to brainstorm and design ideas to

support interacting directly with their natural surroundings. Each group used both Bag of Stuff and Big Paper to design their ideas.

(2.1) Draw attention to specific elements in the child's physical surroundings

Designs can provide prompts to engage children in observational activities within a physical space. For instance, children proposed challenges (e.g., scavenger hunts) that suggest a list of items to photograph, directing users' attention to specific elements in their surroundings. Matt [boy, age 12, Asian] shared the idea of an audio feed that points to natural surroundings nearby: "*This is an audio feature that tells you about things you are looking at.*" Similarly, several children proposed using location, time of day, and season as additional dimensions for challenges to increase engagement with a topic and to draw attention to a certain natural phenomenon, such as phenological cycles (e.g., colored leaves or flowers). Adam wanted the app to "*send challenges to take photos of different colored leaves in the fall, or collect photos of flowers in the spring.*" India proposed having "*maps [in new locations] that unlock when you collect items*" based on your surroundings.

(2.2) Encourage self-directed, sensory interactions with natural elements

Designs can sustain interest in nature by: (1) supporting free-choice explorations, and (2) encouraging physical interactions, such as promoting sensory inspection (e.g. touch, sound, smell) of elements in one's surroundings. During the second co-design session, children who interacted with nature elements wanted the app to support their curiosity and challenge them to identify the nature elements in their photos. Mia [girl, 10, Asian/White] suggested categorization choices to help identify nature elements. She also wanted to use smells to identify the different plants: *"[The] dichotomous key has a button to identify smell…you open it to a plant or flower and it will tell you what it is.*" Adam thought the app should support sound: "*This button is to collect sounds of birds.*"

3.5.3. Design strategies for principle 3: Social interactions

During the third co-design session with children (November, 2016), we explored ideas for social interactions, both in-person and virtually. The focus of this session was to generate ideas for the app to support sharing experiences and playing with others. We asked KidsTeam to prototype ideas for social features for a mobile app. Each group used Big Paper and had mobile screen template printouts to use for prototyping features.

(3.1) Connect users with each other and provide conversational prompts around topics of interest

Designing to support meaningful peer and adult interactions around a shared interest [32] can contribute to recurrent engagements and positive feelings around a topic. We initially assumed children would be most interested in designing social features like chatting and commenting on friends' photos. However, children were more interested in designing features allowing them to friend and play with their peers. Both Adam and Will [boy, age 9, White] wanted the app to help their team as a group "*to go on nature adventures*" and "*collect photos together.*" They proposed having the app display their photos and track their rewards so all team members could view them. Another idea they had was for the app to support their nature explorations through prompts, as Will explains "*the app asks you why is this photo unique…to earn badges.*" Prior work has shown that *conversational* prompts can support learning about nature [55].

(3.2) Create activities that involve two or more users

All children expressed a desire to challenge their peers to match one of their photos. As Matt explained, "*You take a picture of a tree, for example, and you can crop it if you want, then send it to a group of friends and they have to guess what type of tree it is.*" Adding to Matt's idea, other children suggested the app provide reply options for the shared photo. Pamela noted, "*You take photos of nature elements and you send it to your friends and they have to take a picture of the same nature element.*"

Fig. 1. A tactile interaction with a plant while using NatureCollections app.

3.5.4. Design strategies for principle 4: Opportunities for continued engagement

In all three co-design sessions, we explored opportunities for children's recurring engagement with nature.

(4.1) Display children's accumulated progress over time

A child's extended engagement with a particular topic can be rewarded by highlighting completed challenges and providing positive reinforcement. Children suggested ideas to track their progress, such as progress bars displaying completed challenges, a profile displaying earned badges and challenges they have yet to pursue.

(4.2) Promote app engagement across settings

Activities that span multiple days, seasons, and locations can support continued engagement in the topic of interest. For instance, KidsTeam children India and Pamela proposed having challenges to collect items from different locations over multiple days.

4. Applying the interest-centered design framework to the naturecollections application

We employed design strategies that emerged from the co-design sessions to guide the design of a mobile app, NatureCollections, to foster children's interest in nature. The app encourages children to collect nature photos, add descriptive information to photos, and store them in collections. For each principle, we describe select app features and related strategies in braces {} (see Table 1 for a summary of principles, strategies, and app features).

4.1. Design principle 1: Personal relevance

Onboarding Screens: During the onboarding process, a guide character refers to children by their name {1.3} and prompts them to enter their nature interests {1.2} (Fig. 2, Screen 1). These interests are used to tailor which challenges they are presented during later use {1.1}. The character also provides an overview of available activities, badges, and social play {1.3}.

My Collections: Children are then prompted to add their photo to at least one "collection" (i.e., album). The app includes a set of

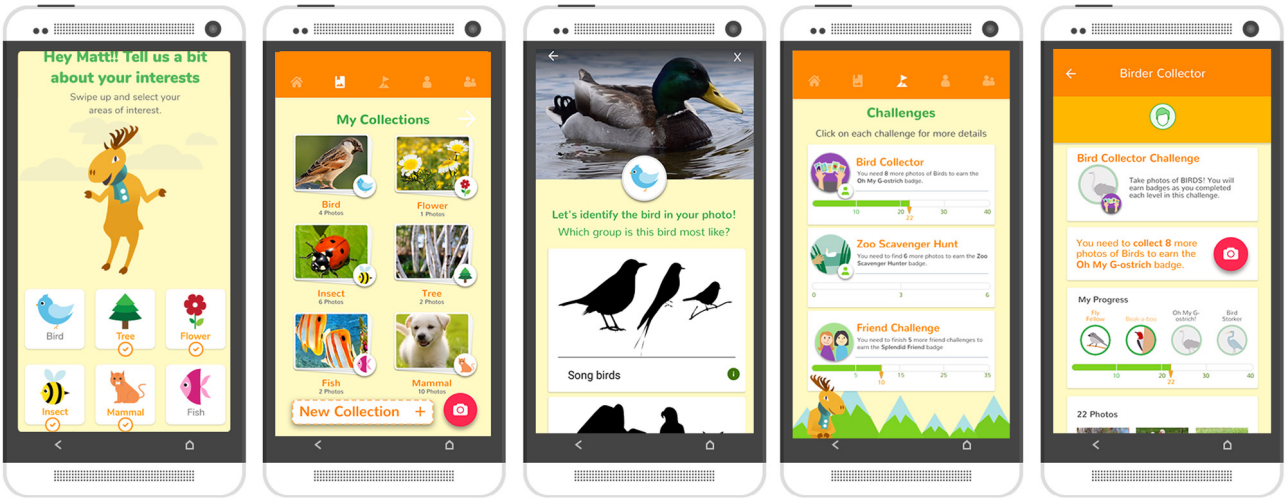

Fig. 2. Screens of the NatureCollections app 1: Onboarding "What are your interests?" 2: My Collections. 3: Photo Classification. 4: Challenges. 5: Challenges details and progress.

standard collections for elements that will likely be present in their physical surroundings (e.g., birds, trees, flowers) {2.1, 4.2}. They are also able to create custom collections {1.1, 2.2}. After saving the photo, children are directed to the "My Collections" screen (Fig. 2, Screen 2), where they can view all photos and associated descriptive text in each collection {4.1}.

4.2. Design principle 2: Focused attention

"Add Details" screen: To focus children's attention on specific nature elements, the "Add Details" screen encourages children to reflect on and articulate observations of their photo {2.1, 2.2}. Children enter descriptive information using conversational prompts, such as a photo title ("What do you want to call this photo?"), caption ("How would you describe this photo?"), and location ("Where did you find this?") {2.2, 3.1, 4.1}.

Photo Classification: To support focused attention and sensory engagement with an element of nature, the app provides a simple classification scheme for children to add additional information to their photo {2.1 2.2}. The classification scheme shown is determined by the preset collection associated with a photo (e.g., bird collection) {4.1}. Children are shown a series of stepped prompts to facilitate classification (Fig. 2, Screen 3). The selected classification choices will show as tags, representing the child's accumulated knowledge.

4.3. Design principle 3: Social interactions

My Friends: To encourage social involvement, the app allows children to add friends through unique usernames, and to view friends' photos and badges on a "My Friends" screen {3.1}. Friends can be part of a team to complete challenges {3.2}. Friends can also challenge one another to match a photo they've taken to earn badges {3.1, 3.2}.

4.4. Design principle 4: Opportunities for continued engagement

Challenges: The "My Challenges" screen presents a set of activities prompting children either to collect photos for a specific collection, classify the nature elements in photos, complete scavenger hunts, or challenge friends (Fig. 2, Screen 4){2.1, 2.2, 3.1}. Challenges appear based on the child's initial interest entered on the onboarding screen {1.1, 2.2}. Each collect or classify challenge has a series of four levels, requiring an increasing photo count to complete each level {1.2, 4.1}. These challenges can be set up for a team of children {3.2}.

Tracking Progress: A progress bar allows children to track their progress as they complete activities spanning days and settings (Fig. 2, Screen 4, 5){4.1, 4.2}.

5. Exploratory in-situ Case study

5.1. CaSe study rationale

Our objective for this exploratory in-situ case study was to investigate how embodying the design principles and strategies in the features of the NatureCollections app may succeed in triggering children's situational interest in nature. We decided to focus our initial exploratory study on this first crucial phase of the interest development model, because (1) a triggered situational interest is a precursor to all other phases of interest development [9], and (2) the relatively short timescale for triggering a situational interest was appropriate for our initial field test of the app [9,10,49,50]. Both Rogers et al. and Klasnja et al. have argued that in-situ studies not only capture the context of use when evaluating a new mobile technology, but often uncover a range of design and usability problems that lab-based evaluations are unlikely to surface [56,57].

5.2. Participants and procedures

We recruited 18 children ages 7–11 (M = 8.7, SD = 1.88, 11 females and 7 males) and their parents through university email listservs and social media announcements shared on nature interest groups and neighborhood parent-social groups. Children were predominantly white (83.0%) and lived in households with a high annual income (47% had an annual household incomes above $150,000), which is reflective of the relatively affluent part of Seattle, Washington, in which this study took place.

We conducted three sessions with children using the NatureCollections app. Each session comprised five to seven children accompanied by their parents, held at a local park. In each session, we explained the study to both parents and children, answered questions, and obtained written consent and child assent from participants. We provided a brief introduction to the activity (i.e., verbal prompts to collect photos), before providing each child with

a device and allowing them to explore the natural setting for 25–30 min. Researchers observed, took field notes, and asked children about their photo choices. There were three to five researchers per session. After the nature photo activity, researchers facilitated a closing group discussion, asking children to reflect on the activity and their app use experiences. We video recorded all sessions and retained children's photos.

5.3. Analysis

In our analysis of the video recordings and photos, we specifically focused on two key behavioral elements of a triggered situational interest: (1) focused attention and (2) social interaction [9]. Within the context of each behavioral element, we noted observational indicators to infer the affective states of participants, such as expressed cheerfulness, playfulness, enthusiasm, and excitement, as well as positive verbal statements. Because of the brief nature of the study and our focus on triggered situational interest, we did not focus our data collection explicitly on Design Principle 4: Opportunities for Continued Engagement.

To analyze the recorded sessions, we drew on video analysis strategies commonly used in the learning sciences, such as interaction analysis [53,58]. Two researchers watched the video recordings, coding for instances of focused attention (attention on nature, device, or people), as observed from behavioral indicators such as focused gaze on an item, the direction of the child's gaze, and verbal communication. We also coded for instances of social interaction mediated by the app use or around nature elements. Through discussion, we identified salient segments for more in-depth analyses. Within these broad, etically defined (deductive) themes, researchers then open coded, allowing for the emergence of emic (inductive) sub-themes [59]. Researchers matched their codes and descriptive observations, resolved any differences, and consolidated sub-themes to reduce overlap and redundancy. Finally, researchers repeatedly viewed the identified video segments to examine triggered situational interest moments, documenting them in detail and noting positive affect indicators.

To complement this analysis, two researchers also analyzed photos taken by children for further evidence of focused attention on nature elements. Researchers collaboratively developed a coding scheme [60], and collaboratively coded each photo as belonging to one of three mutually exclusive categories based on the primary focus of the photo: (1) Selfies; (2) Other people; (3) Nature. Photos that were blurry or that researchers could not agree on were coded as a fourth category: Ambiguous.

6. Findings

For each overarching, etically identified theme, we present salient emic sub-themes that emerged from our analysis. We include vignettes from transcribed video segments to illustrate how elements of a triggered situational interest may be supported by the NatureCollections app, and note indicators of positive affect observed in these moments. We also report photo content analysis results as an additional indicator of direction of attention.

6.1. Focused attention — direction of attention

Participants using the NatureCollections app appeared to have their attention directed outwards, towards their physical surroundings, throughout the sessions. A key behavioral indicator of direction of attention was the direction of the children's gaze.x We observed many instances of children shifting their gaze between the screen and their surroundings, as well as scanning their surroundings for elements of interest, suggesting that their attention was not solely on the device. Shifting of gaze to the device often occurred as children added descriptive information about their photo. Children often shifted their gaze to look at the actual object of interest, not the photo, when making qualitative observations to enter captions for the photo. Observing Emily illustrates this point:

Fig. 3. Primary focus of photos taken by children while using NatureCollections, coded as either other people (n = 12), selfies (n = 0), nature (n = 200), or ambiguous (n = 5).

> *Emily scans her surroundings for elements to photograph. She notices a cluster of spiked seedpods in the tree above her head, and takes a photo of them. When prompted to enter descriptive captions, she looks to her mother for guidance. Her mother, glancing at the app, asks: "What do you want to say about this?" Emily looks up at the seedpods above her head. "Ummm, spiky balls", she replies, and then giggles. "How do you spell spiky?" While Emily enters the caption with the assistance of her mother, several children nearby discuss the crow perched in the branches on the other side of the tree. Emily looks up, away from the screen, then finishes entering the caption. Then, looking up to the far side of the tree, she says, "Oh, if the crow was still there, I could take a picture of it and put it in the bird collection".*

Children's gestures towards and discussion of elements in the environment, as well as exploring their surroundings in search of new objects to photograph were considered behavioral indicators of directed attention. Indicators of positive affect associated with directed attention were observed as children explored their surroundings. Children suggested playful captions (e.g., Emily's "spiky balls"), laughed at photos they or others had taken, or expressed excitement in discovering natural elements.

An interesting element of the data was the occurrence of tactile interactions. While not observed in all children, in several instances, children photographed a nature element that they had physically interacted with in some manner. Several children picked up leaves or touched branches to examine or photograph them, or while using the classification scheme (see Fig. 1), as this vignette shows:

> *Lily and Wade find several rocks and shells on the beach. They place each one in the sand, specifically positioning it for a photograph to highlight texture or lighting, like the iridescent interior side of a shell. Wade comments aloud that he appreciated how crisp and clear a shell appears in his photo, while touching the surface of the shell.*

Lower device literacy and spelling skills presented barriers to some children's directed attention outwards. This was most evident among the younger children, particularly at the "Add Details" screen. Although the app leveraged built-in speech-to-text, the majority of the children opted to enter captions using the keyboard with assistance from their parents.

Our review of children's photos complemented these findings. The majority (92.2%) of all photos taken were clearly of natural elements, whereas only a very small number were of peers and parents (5.2%). An even smaller proportion of photos were coded as ambiguous (2.2%), and no photos were coded as selfies (0%) (see Fig. 3).

6.2. Focused attention — personal relevance

Even while their attention was directed outward towards their physical surroundings, children employed their own individual criteria to choose which objects to focus on and photograph. Children explored their surroundings in search of objects that were interesting or unique, to be worthy of photographing, as this vignette illustrates:

> *David works towards the "Tree Collector" challenge, noting to his mother, "I need one more photo of a tree [to earn a badge]. I took a photo of that one, that one, that one..". as he pointed to specific trees around him. His mother points out several trees he had not indicated. David rejects her suggestions, one after another, articulating specific criteria. In one instance, he couldn't see the base of the tree; in another, he was unable to see the leaves well enough to complete the classification scheme. He leaves the area to search for a different tree to photograph.*

In several instances, children verbally expressed a disinterest in photographing the same object multiple times and sought diversity in photo subjects. In particular, children mentioned the desire to collect photos with a range of different tree shapes, in addition to different individual trees. This suggests the potential for the app to support children's observation of their physical surroundings, as they seek to build diverse photograph collections.

When asked about his experience using NatureCollections, David compared his experience using the app to prior positive experiences using another app: *"It's kinda like PokémonGo except without Pokémon. And in real life. So you collect trees, but as photos… so technically, in a way, it's like PokémonGo, and the Pokémon are the [nature] photos… so it's… NATUREGO!"*

Jessica described her experience with challenges: *"It gives me ideas on what kind of things to take pictures of… so I would look at the badges and take pictures based on how many pictures I needed to get that badge"*. When asked to reflect generally on their children's experience of the app, several parents observed that their children appeared to have greater positive affect when using NatureCollections compared to previous experiences in the same location. As Jessica's mother noted: "*She usually gets bored after 10 min of being at the park and wants to go home, but with this app she seemed to be engaged and running around looking for things to take photos of*".

Although challenges prompted children to notice categories of elements, the children themselves chose the categories on which to focus. When asked, children explained their behavior in terms of positive affect, some expressing enjoyment of earning badges, and others expressing pleasure and interest in finding nature elements (e.g. flowers). Some seemed uninterested in the challenges or badges in general. Instead of adding their photos to pre-set collections, they created personally meaningful, custom collections (e.g., beach, feathers), searching for things that were unique or interesting to them.

6.3. Social interactions — peer engagement

Although most of the children did not know each other before the session, they began interacting with the peers they met, looking for elements to take photos of together and sharing their screens with each other to show their photos and badges. Discussions between children included what they had photographed or would photograph next, and in which collection they would save the photo. Cooperative interactions also occurred, in which children collaborated to use the classification scheme to identify the elements in the photo they had taken.

Indicators of positive affect were most often observed in association with these social behaviors. Peer interactions tended to be playful, and instances of energetic interactions were most often observed among younger children in pair and group interactions. However, some children preferred to interact with their parent only. Most of the children who discovered the "Add Friends" feature quickly asked peers for their username and added them to their app. Children were generally less interested in taking pictures of people (see Fig. 3), but a couple of children took photos of their parents and peers, adding them to their 'Mammal' collection or creating a custom collection for people, and often entering playful captions (e.g., "North Face Mom" and "Penguin Emojis").

6.4. Social interactions — parent–child engagement

Parent–child interactions observed in the NatureCollections sessions varied across dyads. Some children appeared more dependent on their parents; this was most apparent in requests for direction and suggestions for photo subject, appropriate collections for photos, and descriptive text in the "Add Details" screen. Beyond directional suggestions, some parents supported close observations of specific elements in nature, as this vignette shows:

> *Yuri photographs a feather she found and works with her father to add details to the photo. After entering a title, her father says, "And then if you want to say something about it, that's what 'caption' means. Do you want to say something about it?" Yuri hesitates. He continues, "Like… we didn't put anything in here to tell us how big it is, right?" Yuri turns from the device and looks at the feather. "Small…" Her father replies, "Yeah, you could say small, or two inches, or something. That's a good idea".*

Interestingly, parents also facilitated broader conversations around nature, such as which objects should be considered "nature" (e.g., Does a rock count as nature? Should the child take a photo of garbage and place it in a custom "litter" collection?). These conversations ranged from instructional to collaborative.

7. Discussion

The primary contributions of the current work are (1) an interest-centered design framework consisting of four theoretically derived design principles and a set of empirically based design strategies to implement each principle, and (2) empirical insights from a case study that applied the interest-centered design framework to design, develop, and evaluate the NatureCollections app. The interest-centered design framework can be used in the development of future mobile technologies that support children's interest-driven participation in informal learning settings, such as in nature. Our interest-centered design framework addresses the persistent problem of excessive interactions with mobile screens in nature [27,28], a major obstacle to supporting the kind of focused attention that is required for interest development and interest-driven learning [9]. Our framework leverages other aspects critical to sparking and sustaining interest development, such as personal relevance, social interaction, and opportunities for continued engagement [9].

Guided by our interest-centered design framework, we developed NatureCollections, a mobile application that encourages children to explore the natural world by creating, curating, and sharing nature photo collections. Through an exploratory in-situ case study, we assessed whether NatureCollections may contribute to triggering children's situational interest in nature. Our results showed that NatureCollections succeeded in drawing children's attention to and close observation of their natural surroundings. Specifically, we found evidence of children's visual scanning of the environment, as well as tactile interactions with nature elements, such as feeling shells and sand texture, and holding branches and

leaves in the process of making classification decisions. Children also engaged in nature-themed social interactions with their peers and parents as they used the app, showing how focused attention can go hand in hand with social engagement. Children demonstrated enjoyment while using the NatureCollections activities, including playful social interactions around nature with parents and peers.

Several features of the app contributed to these results. First, children's experiences with the app were highly personalized (e.g., Onboarding screens, My Collections), a key factor in both interest development and interest-driven learning [9,20]. They could choose what to photograph, which collections to build, and which challenges to pursue. Tracking accomplishments and earning badges contributed further to the personalized experience, particularly for older children. In prior work, children's experiences were not so highly personalized [24,26,36,44,47]. We also identified supporting self-directed exploration and choices as being key to fostering situational interest. We acknowledge that one reason for this difference between NatureCollections and prior related work is the absence of a structured curriculum associated with NatureCollections. In our study, we did not dictate what children should photograph in part because we had no set learning objectives. Whereas prior work in mobile learning technologies has emphasized designing for scientific inquiry [24,33,34,36,37,43,47], our primary objective in the design of NatureCollections was to emphasize interest development, a critical component of interest-driven learning [9]. Nevertheless, we believe educators could use NatureCollections successfully in the context of a curriculum and associated learning goals without diminishing the personalized experience we observed in our study. The setting must be chosen carefully to align with the curriculum and children to be given autonomy within that setting to create, collect, and classify photographs that are most appealing to them. Follow up lessons could leverage children's photographs for further learning opportunities.

NatureCollections designs encouraged children to attend closely to their surroundings and engage in nature-based social activities. For instance, the "Add Details" feature of the app allowed children to describe their photographed nature element in their own terms and reflect on what they had photographed. When engaging with this feature, children prolonged their gaze and inspection of the nature element. They also engaged in conversations with peers and parents about the object of inspection. This feature contrasts to features used in prior work, such as AR features overlaid onto the natural world [24] and just-in-time information to supplement the object of investigation [46,47]. Such features can distract the learner from attending to the natural elements in front of them [27,28,36]. Unfortunately, in the current iteration of NatureCollections, younger children with lower language and device literacy found text entry challenging to use. Future work on NatureCollections is needed to design for a wider range of literacy skills.

8. Limitations and future work

We recruited participants through convenience sampling, and although their demographic characteristics are reflective of Seattle, they do not reflect the demographic characteristics of the United States. We also did not have knowledge of children's prior interests. Therefore, it is unclear if individual instances of photo preference were determined by a triggered interest or by a preexisting personal interest. In this study, our intent was to explore how the embodiment of design strategies may support focused attention and social interactions in triggering a situational interest. Another limitation of this study pertains to inferring children's positive affect indirectly through observed behaviors. Thus, we cannot untangle factors contributing to positive affect. These factors, include app factors (e.g., feature design, gamification elements), environmental factors (e.g., nature setting, weather, daylight), activity and social factors (e.g., interactions with parents, peers, and researchers), among others. However, overall experiential positive affect is important to suggest a triggered situational interest [9].

The current study focused on evaluating the NatureCollections app design in triggering situational interest, the first phase of interest development. Thus, it is appropriate to focus on observed short-term behavior change [56]. In future work, we will deploy the NatureCollections over a longer period of time to determine whether it can support the remaining three phases of interest development in comparison to a control group. Central to progression through these phases is encouraging and providing opportunities for continued engagement in an activity [9]. Guided by our interest-centered design framework, we designed features such as challenges and friending to provide such opportunities. Ultimately, our goal is to use NatureCollections to support children's well-developed individual interest in nature and support designers who wish to create technologies that facilitate interest development.

9. Conclusion

In the current work, we have presented an interest-centered design framework to guide the design of mobile technologies to support children's interest development. We have shown how the framework successfully guided the design of the NatureCollections mobile app. Through an exploratory in-situ case study, we found evidence that NatureCollections contributed to triggering children's situational interest in nature. Although we have focused on interest development rather than scientific inquiry, we believe that future work on mobile learning technologies can leverage these insights to design for interest-driven learning. Failure to take interest development into account may thwart efforts to provide rich learning experiences with mobile learning technologies.

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Conflict of interest

No author associated with this paper has disclosed any potential or pertinent conflicts which may be perceived to have impending conflict with this work. For full disclosure statements refer to http://dx.doi.org/10.1016/j.ijcci.2019.01.003.

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