"Otter this World": Can a Mobile Application Promote Children's Connectedness to Nature?

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ABSTRACT

Can a mobile application encourage children to spend more time outdoors and promote their connectedness to nature? In this paper, we present results from a three-week experimental deployment study of *NatureCollections*, a mobile application that allows users to build, curate, and share nature photo collections. Twenty-eight children (aged 9-12) and their parents participated in the study; 15 used the NatureCollections app, and 13 used a basic Photo app. We found that the NatureCollections app significantly increased the time children spent outdoors compared to the Photo app. Children in both groups said they felt happy and excited about spending time in nature. However, children in the NatureCollections group reported that time spent outside with the app increased their curiosity about the types of species and plants they saw and photographed. Children in the NatureCollections group also engaged in nature-based conversations with their parents, and even sought to look up information online about the plants and animals they observed. In contrast, children in the basic Photo app group did not display this level of curiosity about what they saw in nature, and the photos they took were driven largely by the aesthetic qualities of nature elements. Our results suggest that NatureCollections promotes and supports children's connectedness to nature.

Author Keywords

Child-computer interaction; Outdoor mobile technologies; Nature-based exploration; Human-nature connection.

CSS CONCEPTS

•Human-centered computing~Human computer interaction (HCI)~HCI design and evaluation methods~Field studies

INTRODUCTION

Prior work shows that spending regular time in nature benefits children's overall health and wellbeing [5,20,35,57]. Time in nature positively supports children's learning, attention, physical health, and mental and emotional

Figure 1: Example of close observation: A child directs her attention to the tree leaves in the process of making a classification of the type of tree.

wellbeing [3,5,11,15,20,28,55]. Moreover, children's direct experiences with nature increase their feelings of connection to and concern for nature [8,12,36,37,41,58]. This is important, because children who feel connected to nature have lower stress levels, reduced aggression, and they feel happier [5,15,39,57]. They are also more likely to take positive actions towards the environment as adults [4,36,54,59]. In light of the extreme weather patterns we are currently witnessing across the globe as a result of climate change, efforts to promote the next generation's connectedness to and stewardship of nature take on an added urgency [39,65,66].

Unfortunately, children today are spending less and less time in contact with the natural world than previous generations [33,52,64,67]. Factors contributing to children's decreased time in nature include busy schedules, fewer opportunities to access outdoor spaces in urban areas, parental safety concerns, and increased screen time [29,33,52,64,67,68]. One survey of youth across the United States found that 80% of children reported feeling uncomfortable being outside due to weather conditions or bugs, and 49% of children are simply not interested in spending time in nature [64,68]. Although common wisdom places blame on interactive technologies for keeping children indoors [36,53], the current study explores how these very technologies might be

leveraged to get children outside and engaging in meaningful, enjoyable experiences in nature.

This work joins a growing body of prior research in Child-Computer Interaction exploring the potential for mobile interactive technologies to engage children in outdoor experiences. Prior research recognizes that, although technologies are often seen as the culprit, keeping children indoors and sedentary in front of a screen, they can also be used to encourage active experiences outside [2,47,60]. Researchers have explored ways to design interactive experiences that mirror traditional game-play patterns, encourage children's social interactions, and increase their physical activity [1,13,19,30,48,49,56,60]. Another body of work has explored ways to leverage mobile technologies and augmented reality in an effort to support children's engagement in outdoor science inquiry [17,25,31,43,61,62]. We could find only one exploratory study that examined what motivates children to connect with nature and the possible role of technology in promoting greater connection to nature [14]. To the best of our knowledge, no prior work has systematically designed and evaluated a mobile application's ability to get children outside and increase their connectedness to nature.

We designed *NatureCollections*, a mobile application that allows children to build and curate photo collections, and classify and describe their nature photos [27]. In an initial pilot study of NatureCollections, we found evidence that the app encouraged child-directed engagement with and close attention to the natural elements in their surroundings–a key component of child-nature connectedness [23]. The current study examines children's longer-term engagement with NatureCollections, focusing specifically on how the app impacted children's time spent outside and their interactions with nature. Our aim in designing NatureCollections is to influence children's connectedness to and positive interactions with nature. We ask the following research questions—*RQ1:* Does the NatureCollections app succeed at getting children to spend more time outside? *RQ2:* Does NatureCollections impact children's connectedness to nature?

We conducted a three-week experimental deployment study with 28 children (aged 9-12 years) and their parents. We asked parents to record their child's daily time outside for the first week, after which we randomly assigned equal child-parent pairs to either receive the NatureCollections app or a basic Photo app (allowing children to take still photos and view them in a photo gallery) to use for two weeks. Parents continued to record their child's daily time spent outside with the app for the duration of the study. We used a multiple baseline experimental design, where the start date of the study was staggered over two weeks across three groups of families divided equally between conditions. During the two weeks, while children used the apps, we employed ecological momentary assessments (surveys pushed directly to participants' devices) to solicit real-time feedback about

children's app and outdoor experiences. Children had the option to record an audio reflection further explaining their responses. At the end of the study, children participated in an outdoor activity on the campus of the research team's university, which provided further opportunity for them to share their thoughts about and experiences with the app.

Children in both groups said they felt happy and excited about spending time in nature. However, children in the NatureCollections group reported that time spent outside with the app increased their curiosity about the types of species and plants they saw and photographed. We observed evidence of this curiosity in the post-intervention activity with the children in the NatureCollections group. Children in the NatureCollections group also engaged in nature-based conversations with their parents and even sought to look up information online about the plants and animals they observed. In contrast, children in the basic Photo app group did not display this level of curiosity about what they observed in nature, and the photos they took were driven largely by the aesthetic qualities of natural elements.

This work contributes empirical evidence from an in-situ deployment of NatureCollections showing that the app succeeded at getting children outside and interacting with nature in a positive, curious, and engaged way. This is the only work we know of that examines the potential for a mobile application to increase children's time spent outdoors and promote their connectedness to nature.

RELTAED WORK

Children's Connection to Nature
In the last few decades, environmental psychologists and scientists have become increasingly interested in understanding how people form and experience a connection to nature, what is often referred to as a *human-nature connection* (HNC). HNC broadly refers to a sense of interconnectedness between one's self and nature. Some researchers have offered an evolutionary explanation (i.e. humans have an innate tendency to seek connections with nature) [63]. Other researchers have focused on psychological dimensions of HNC, including constructs such as inclusion with nature [45], environmental identity [10], and nature relatedness [41]. Research using a variety of HNC measures consistently finds that the amount and frequency of time spent in nature plays a critical role in fostering a sense of connection between humans and nature, e.g.[24,41,51].

Across the diverse approaches to understanding HNC in environmental and conservation psychology, all approaches agree on (1) the importance of repeated direct nature interactions and experiences during childhood, and (2) the essential role that HNC plays in establishing pro-environmental choices and behaviors in adulthood [18,21,51]. Direct experiences with nature during childhood represent fundamental moments for creating a long-term connection with nature, and, ultimately, becoming committed stewards of the environment.

Although childhood is recognized as a critical period for developing a connection to nature, most existing work exploring HNC does not focus specifically on children [18,21]. One exception is Giusti et al.'s framework [18], assessing where and how children connect to nature. In addition to its focus on children, this framework distinguishes itself from other work by characterizing the specific kind of experiences that people tend to connect to while in nature, as well as a recognition of the connection between children's mind, body, and nature experiences [18].

Giusti's framework depicts HNC as an *ability* and identifies a group of specific abilities displayed by children who are connected to nature. Examples include "being curious about nature" and "knowing about nature." In Giusti et al.'s terms, one would say that a child connected to nature is capable of being curious about nature (first ability) and capable of knowing about nature (second ability).

Closely related to HNC abilities are specific *qualities* of nature-based activities that have a high potential to connect children to nature. They include nature-based experiences that are child-driven (i.e., chosen by the child), engage children's senses (e.g. touch, hearing), and fun, joyful, or amusing. If children's nature-based experiences exhibit these qualities, they are more likely to demonstrate HNC-related abilities. In other words, abilities reside in children, whereas qualities are aspects of the nature-based experience.

A key principle to Giusti's framework is that children's HNC abilities progress over time and as they engage with nature. The framework divides this progression into three consecutive phases: (1) *being IN nature*, (2) *being WITH nature*, and (3) *being FOR nature*. Each phase is marked by a distinct set of HNC abilities. For instance, during the first phase—being IN nature—children demonstrate a curiosity to explore their natural surroundings. Each of the three phases in the framework is sequential in its order of development and progress. For children to feel motivated to act FOR nature (the 3rd phase), they must first develop the abilities to (1) feel comfortable being in the natural elements of the outdoors, i.e., being IN nature during the 1st phase, and (2) feel concern for the environment, i.e., being WITH nature during the 2nd phase. Therefore, children's ability to be curious about nature is key to developing a profound human-nature connection [18]. Below, we identify the child-related abilities associated with each phase of Giusti et al.'s HNC framework, as well as the qualities of nature-based activities that support these abilities.

Being IN Nature

Child-related abilities: Children's HNC-related abilities include feeling comfortable in natural spaces (e.g. with dirt, mud or bugs) and being curious about nature.

Qualities of nature-based experiences: Significant nature-based activities in this phase of the framework are characterized by being child-driven, enjoyable, engaging children's senses (e.g. touch, hearing), involvement of animals, and drawing children's attention. These experiences are often accompanied by a sense of awe or "wow effect."

Being WITH Nature

Child-related abilities: Children's HNC-related abilities include acting in natural spaces (e.g. nature play), feeling attached to natural spaces, reading natural spaces, knowing about nature (like animals or plants), and recalling memories with nature.

Qualities of nature-based experiences: Significant nature-based activities in this phase are characterized by being child-driven, engaging children's senses, as well as involving creative expression and physical activity.

Being FOR Nature

Child-related abilities: Children's HNC-related abilities include caring about nature, taking care of nature, and being one with nature.

Qualities of nature-based activities: Significant nature-based activities in the third phase of the framework are characterized by thought-provocation, structure/instruction, and social/ cultural endorsement.

In our current study, we focused specifically on the first phase of children's HNC-related abilities: being IN nature. The abilities that children develop during this phase are a necessary precursor to their development of all subsequent abilities. Therefore, they represent a critical aspect of human-nature connection. Our decision was also guided, in part, by logistical considerations, which limited the study period to three weeks (one pre-intervention week and two intervention weeks). According to Giusti et al., it takes at least two weeks of direct nature interactions and experiences to develop children's HNC-related abilities beyond the first phase of being IN nature [18].

Technology Design for Outdoor Settings
The Child-Computer Interaction field has a long-standing research tradition of harnessing the affordances of interactive technologies—including mobile technologies, tangibles, sensors, and augmented reality—to engage children in outdoor social play and to support children's science inquiry. However, there is little work that specifically explores the role of interactive technologies in connecting children to nature. Informed by prior research in outdoor settings, our work aims to fill this gap through the design of a mobile application, NatureCollections, that supports children's nature explorations and connects them to nature.

Designing Technologies For Outdoor Play

Interaction design projects for outdoor settings have focused on encouraging children's physical and social play by leveraging a variety of technologies, including mobile, augmented reality, tangibles, and sensor-based devices. Heads-up games like *Camelot* [56], *RaPIDO* [49], and *Scratch Node* [19] promote outdoor gaming with the support of screenless digital devices with the aim of keeping the

player's head "up" (i.e., not looking down at a screen) for physical activity, outdoor social play, and embodied interactions. Pervasive games such as *Geocaching* [42] and *PacMap* [7] harness location-awareness capabilities with the aid of GPS and/or WiFi devices to allow players to collect rewards or treasures hidden in the physical world. Other pervasive games, such as *Ingress* [26] and *Pokémon Go* [47], use mobile devices with augmented reality features that overlay a co-located game landscape and characters onto the physical surrounding. For example, Pokémon Go makes use of just-in-time, location-based prompts of relevant content, such as the existence of a nearby raid battle. Across these efforts, researchers aim to support social interaction, creative thinking, and physical activity in outdoor game play.

Designing Technologies For Outdoor Learning

Projects that support environmental and science inquiry, such as *iBeacons* [61], *Tree Investigators* [62], *GeoTagger* [17], and *EcoMOBILE* [25], aimed at leveraging mobile and augmented reality (AR) capabilities to guide learners during outdoor field explorations. In several of these projects, mobile devices augment real-world locations with an overlay of virtual information and narratives to support scientific observations in the learner's physical setting [25,61,62]. For example, Tree Investigators and EcoMOBILE researchers reported that AR design elements enhanced learners' engagement in their scientific inquiry and observations of their surroundings. Other projects, such as iBeacons and *Tangible Flags*, presented learning activities to children based on their proximity to relevant nature elements or places [9,61]. Researchers across these projects designed features to support children's scientific data collection and analysis, as well as features that increased children's interactions with peers during a field trip [9,17,43,61,62].

Beyond this focus on embodied physical play and learning outcomes, designing technologies that promote children's interactions with and connectedness to nature remains a new and underexplored area of child-computer interaction research. Harnessing the capabilities of mobile technologies, NatureCollections contributes new insights into designing interactive technologies that support children's nature interactions and explorations.

NatureCollections App

Guided by an interest-centered design framework and co-design sessions with children [27], we designed the features of the NatureCollections app to promote children's interest in and engagement with nature. NatureCollections allows children to take photographs of things they see in nature, classify the plants and animals in their photographs, and organize them into themed photo albums such as birds, insects, and trees. The app lets children personalize and customize their app experience. For instance, during the NatureCollections onboarding process, a friendly moose character addresses children by their first name, introduces himself as their nature app guide, and prompts them to enter their interests. These interests are used to tailor the
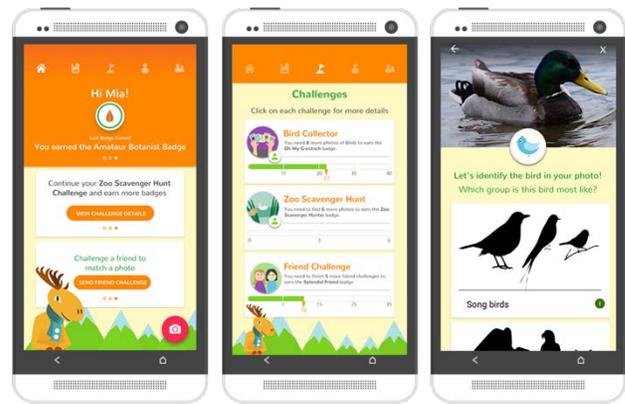

Figure 2: Screens of the NatureCollections app 1: HomePage showing interest-based challenges 2: My Challenges. 3: Classification details.

"Challenges" presented to children on the app home page to support child-driven interactions with nature (Figure 2.1, 2.2). Children can create and organize their photographs into customized "My Collections" that reflect their specific blend of interests. In addition, the app includes a personalized "Profile Page" where children can track their accomplishments, including photos taken, badges earned, and challenges completed.

Our primary goal with a number of designed NC features is to direct children's interactions and provide opportunities for sparking curiosity as well as prolonged engagement with nature. For instance, the "Add Details" feature allows children to enter descriptive information about their photo into text fields using conversational prompts (e.g., "How would you describe this photo?"). This feature encourages children's curiosity to examine the subject of their photo carefully and reflect on specific elements. The "Photo Classification" feature similarly encourages children to direct their attention to details of the natural element by providing simple classification schemes for each preset photo collection (See Figure 2.3). These schemes guide users through a series of stepped prompts containing visual silhouettes to facilitate classification. Challenge types span multiple seasons and locations to promote app engagement across nature settings and over time. Children can view their photos taken for challenges and track their progress toward a challenge goal on the "Detail Page."

Photo App

We developed a second, basic Photo app (also titled NatureCollections with the same app icon) to test whether the behaviors we observed in this study were due to the NatureCollections app features, or whether they were instead attributable to the novelty of being given a smartphone and prompted to photograph one's natural surroundings [14,24]. The Photo app consisted of two main features: (1) a camera feature with only a single shot (no other photo capture modes, filters, or video capabilities), and (2) a photo gallery displaying a grid of all photos taken.

METHOD

We recruited 32 children between the ages of 9 and 12, and one of their parents (one child-parent pair per family) to participate in the study. Twenty-eight families (15 = NC app; 13 = Photo app) completed all the procedures and were included in our final sample. Of the families who dropped out of the study, one (Photo app) did so in the first week before the child received the phone. The second family dropped out after receiving the phone and the child never used the app (Photo app). The last two families (Photo app, NC app) did not complete the final interviews and dropped out in the last week of the study after their children used the app (Table 2).

Demographic Variable		NC N	Photo N
Gender	Female	9	9
	Male	6	4
Age	Age 9	8	3
	Age 10	5	5
	Age 11	0	2
	Age 12	2	3
Race	White or Caucasian	8	8
	Black or African American	1	0
	Asian / Pacific Islander	1	1
	Mixed	5	4
Household Income (US$)	Less than $25,000	1	0
	$25,000 to $49,999	0	0
	$50,000 to $74,999	2	5
	$75,000 to $99,999	1	1
	$100,000 to $149,999	4	2
	$150,000 or more	7	5
Parent's Education	High school graduate	1	0
	Trade /Vocational	3	1
	Associate's degree	2	0
	Bachelor's degree	5	8
	Graduate degree	4	4
Child Lives with Parent	Yes, Full-Time	14	13
	Yes, Part-Time	1	0

Table 1: Demographic characteristics of participants

We used a variety of strategies to recruit participants. We posted the study announcement on the authors' school website, and it was shared via a campus-wide news post as well as email listserv. Authors posted the announcement on their personal social media accounts and on local parent Facebook groups. We also distributed flyers at local libraries, schools, and community centers throughout the metropolitan region where the study took place.

Once interested families (a total of 164) signed up for the study, we divided them into two groups: those children who reported having their own handheld smart device (e.g. smartphone or iPod touch) and children who did not own a smart device. We then emailed an equal number of families from each group in the order in which they signed up to schedule the initial interview. Our initial data sample included equal numbers of children from each group. We gave families the option of coming to campus or meeting at their neighborhood library for their initial interview. It took 3 weeks to schedule and complete these initial interviews.

We attempted to recruit a diverse sample with respect to race, household income, and education level. Our final sample skewed towards upper- and middle-class families; however, it mirrors the race distribution of the city [69]. Table 1 shows participants' demographics. Families received a $25 gift card after completing the initial interview and the first week of the study, and a $50 gift card once they completed the final interviews.

Study Design

We conducted a three-week experimental study in which we used a stratified random sampling approach to assign an equal number of participants to one of two conditions: (1) the intervention group, who received the NatureCollections (NC) app (NC condition), or (2) the active control group, who received a basic Photo app (Photo condition). Within each condition, children were equally distributed based on the following factors: (1) whether they had their own handheld device; (2) whether they were an only child or had siblings; and (3) their birth order in the family.

Of the participants who finished the study, 15 were in the NG condition and 13 were in the Photo condition. We chose to include an active control group to determine whether the novelty of being given a smartphone and being prompted to take pictures of nature would, on its own, impact children's time outside and interactions with nature [22].

To eliminate any recorded changes or differences between app conditions due to chance, we used a multiple baseline experimental design, where the start date of the three-week study was staggered over two weeks across three groups of families (10, 10, and 8 families who completed the study in each group). The app condition was randomly assigned to equal numbers of families within each of the three groups. See Table 2 for details on condition assignment and group start dates.

The experiment was a 2x2 mixed factorial design with the following factors and levels:

- *Condition*: NC, Photo
- *Intervention*: Pre, Post

The between-subjects factor was the app condition (either NC or Photo), and the within-subjects factor was the intervention period, as both groups submitted journal entries during baseline and intervention phases. We also collected three measures of children's behaviors during both baseline and intervention periods: (1) time spent outside, (2) time

spent on technology (both measured by self-reported diary entries from parents [44]), and (3) during the intervention period, we collected time spent on the assigned app (measured by app log data from children's devices).

Group	NG N	Ph N	W N	Total N
Week 1	5	4	2/Ph	12
Week 2	5	5		10
Week 3	4	4	1/Ph, 1NC	10
Total	15	13	4	32

Note. NC: NatureCollections, Ph: Photo app, W: Withdrew.

Table 2: Group start dates

Study Procedures

Parent diary entries: During the first week, we asked parents, with the help of their child, to fill out a daily journal of their child's total time outside and type of outdoor activities, as well as time spent using screen-based technologies, and type of tech-based activity. The goal was to establish a stable baseline of these activities for each child in our sample before introducing the app condition. In the second week, families received (either in person or in the mail) a phone with either the NatureCollections or the Photo app installed.

Parent-child pairs were asked to continue filling out the daily journal throughout the second and third weeks. In addition to recording children's total time outdoors, they were asked to report instances of using the NatureCollections/Photo app, including time, location, and a brief description of the context of use. We collected 21 diary entries per parent-child pair, for a total of 588 entries from all participants. Five parent-child pairs missed a total of 25 entries.

Log data: Both the NC app and the Photo app logged all of the children's interactions and input into the phone. These data included time on app, features used, and geo- and time-stamped photos taken by each child. Our NC app has a backend server to store user data once the device is connected to WiFi. We used Firebase to store the data from the Photo app.

Ecological momentary assessment (EMA): EMA involves repeated sampling of participants' in-situ, real-time behaviors and experiences [44]. Over the two-week period, children were asked to periodically complete two short surveys, detailed below, using the study phone at specific times: after their first app use, then twice during the two-week app use period and one final time on the last day of the study. We used the Snap Mobile Anywhere Survey app,

which captures audio responses to questions and does not require cell phone data to submit. The two surveys we administered were:

(1) audio reflections: The first survey had three audio reflection questions asking children to (a) describe what photos they had taken and why; (b) things they liked about the app; and (c) things they disliked.

(2) outdoor experiences: The second survey asked children about their outdoor time using the app. We asked (a) if they feel happy or less happy to go outside, (b) if they'd like More time or Less time in nature, and (c) if they feel very excited or not excited to use the app in nature. For each of these questions, children had the option to record an audio reflection further explaining their answers.

Children's post-experiment outdoor activity: After completing all experimental procedures, parents and children were invited to participate in a final, audio-recorded interview held at the university campus. Parents were asked about their family experiences having their child use the assigned app and clarifying questions about their daily journal entries. While parents were being interviewed, children participated in an outdoor activity in which they showed a researcher how they used the app and shared their thoughts and experiences around their app engagement. Those activities were audio- and video-recorded. The final interviews were completed within a few days of the experimental phase of the study and over a total period of 5 weeks due to participants' staggered start dates and to accommodate families' commitments and travel dates.

Data Analysis

Parent diary entries & log data: We used the parent diary entries and phone usage logs to construct a dataset of app use for each child. We used these datasets to conduct an analysis of children's total time spent outside during the baseline and intervention periods (pre- and post-app use). For the missing data entries (discussed above), we utilized multiple imputations using the expectation-maximization algorithm to substitute those data points [40]. Because the data were not normally distributed, we first performed a log transformation. We used block ANOVA to account for non-independence of our data points (multiple data points per child across the study period), with condition (NC and Photo app) as the independent variable and intervention period (pre- and post-app use) as the blocking factor.

Children's post-experiment outdoor activity: We completed 28 post-child outdoor activities and interviews that were video- and audio-recorded (ranging from 25 to 45 minutes). One researcher transcribed 4 post-child activity videos from each app condition verbatim and added descriptions of the non-verbal actions of the child with their surroundings (total of 8 post-child activity videos). Using a grounded theory approach [6], two researchers then openly coded two transcripts from each app condition (total of four transcripts) to identify emergent themes. The researchers came together

to review their coding, combine themes where appropriate, and come to consensus on an initial list of themes (e.g. nature captures child's attention; child demonstrates curiosity about nature; child-directed nature exploration). They applied this consensus list of themes to the remaining four transcripts (2 from each group) and checked whether any new themes emerged. The researchers came together once more to discuss and come to consensus on the newly identified themes. They divided the remaining videos and coded them separately, checking in regularly to ensure consensus was maintained [46].

Following this open coding process, researchers organized the emergent codes into hierarchical themes aligned with Giusti et al.'s framework. We focused in particular on themes related to abilities and qualities associated with the first phase of being IN nature. [18]. For example, emergent codes that focused on child-initiated app use in nature aligned with the "child-driven" quality of significant nature-based activities.

Ecological momentary assessment (EMA): Children completed a combined total of 198 audio surveys with a total of 534 individual audio files, with a response duration ranging from a few seconds to 2.6 minutes. In 50 surveys (115 audio recordings), the participant IDs were not captured, and one audio file was corrupted. However, we were able to identify the app condition (NC or Photo) for 34 of these 50 surveys (67 recordings). 56% of the total surveys came from the NC app condition, and 43% came from the Photo app condition.

We transcribed all audio clips before analyzing them. Two researchers individually coded the same 30 audio clips selected randomly from each app condition (a total of 60 audio clips) using the same coding scheme developed for the post-experiment outdoor activity. We met to discuss and achieve consensus on code definition and application, resolve disagreements of any coded clips, and assess inter-rater agreement. Inter-rater agreement was satisfactorily high ($\kappa = 0.81$) [32]. After this process, one researcher coded the remaining 474 audio clips.

RESULTS

RQ1.: Does the NatureCollections app succeed at getting children to spend more time outside?

Children's Time Spent Outside

During the first week of the study, before receiving the app (pre-intervention), children in the NG app group spent an average of 2 hours 7 minutes outside per day (sd = 105.38 mins). Children in the Photo app group spent an average of 2 hours 4 minutes outside per day (sd = 129.15 mins). This difference was not statistically significant ($p = .482$).

We used block ANOVA to account for the non-independence of our data points (multiple data points per child across the study period), with condition (NC and Photo app) as the independent variable and baseline and

intervention periods (pre- and post-app use) as the blocking factor. Children in the Photo app group averaged 2 hours 6 minutes per day outside during the intervention period. This amount of time did not differ to a statistically significant degree from the average amount of time this group of children spent outside during the baseline period (F (1,193) = 10.551 p= .657). However, there was a statistically significant difference in the average amount of time that children in the NC app group spent outside between the baseline and intervention periods (mean = 2h 48min, sd =132.67, F (1, 389) = 12.153, $p < .001$, η2 = .026). In other words, the NC app group spent more time outside, on average, after they received the app.

During the post-intervention outdoor activity, children in the NC app group explained that having the app encouraged them to go outside more often. One 12-year-old girl reflected on her experience using the NC app: "*It's pretty fun to use, it really gets you outside, too.*" Another child, when asked how often he went outside during the study, responded: "*Every day actually, yes this app brought me outside more*" (boy, age 10). In the NC group, 86% of the children used the app frequently over the two-week intervention period, particularly at the beginning of the study and at the end.

In contrast, the Photo app group did not express similar motivation to spend time outside during the intervention period. Approximately 75% of the children in this group stopped using the app after the first couple of times. One ten-year-old girl described her experience with the Photo app: "*Usually I would spend about three hours a day outside without even using the app. The app didn't really help me spending more time outside.*"

RQ 2.: Does the NatureCollections app impact children's connectedness to nature?

We present the results of our qualitative analysis of children's in-situ audio responses during the two-week period of app use, as well as children's responses during the post-intervention outdoor activity. Results are organized thematically around the abilities and qualities from Giusti et al.'s framework that we identified in our data. We focus on the first phase of the framework, *being IN nature.*

Being IN Nature

We present our results for each app condition, organized by children's HNC-related abilities related to the first phase of Giusti et al.'s framework, *being IN nature.* The abilities in this phase include *being curious about nature* and *feeling comfortable in natural spaces* (e.g., with dirt, mud or bugs). We include discussion of the specific qualities of nature-based experiences that supported each of these abilities.

Being IN Nature: Showing Curiosity About Nature

NatureCollections app group. In addition to encouraging children to go outside, the NC app sparked children's curiosity about natural spaces and motivated them to learn about and explore nature. One 12-year-old boy explained: "*I like using the app because it motivates me to go outside and*

learn more about what I'm taking photos of." With respect to the qualities of children's nature-based experiences that supported their curiosity, the NC app succeeded in *drawing children's attention to nature* and encouraging them to engage *in child-driven explorations of nature.*

The NC app helped draw children's attention to the natural elements in their surroundings. For instance, one 10-year-old boy reflected on his app experience during the post-intervention outdoor activity: "*I notice things differently since I started using the app, like types of animals and trees.*" NC app features like "Add Details," "Classifications," and "More Information" drew children's attention to different types of nature elements. One 10-year-old girl reflected on her connection to nature while using the app: "*When I use the NC app, I feel pretty connected to nature because I'm taking pictures of nature and identifying them and placing them into groups and learning more about the plants. Because I have to observe it and really try to understand more about it.*"

During the post-intervention outdoor activity, one 9-year-old girl noted that she liked how the classification feature drew her attention to details in nature: "*I like the classify part, like what type is it, how many pairs of wings does it have [referring to bug classification], what do the leaves look like.*" Another 10-year-old boy commented: "*I look at things more and notice more things, like animals, bugs and stuff.*" In a similar manner, one 9-year-old girl excitedly shared her app experience: "*It was pretty great, I liked how you were trying to get kids to nature…to..to figure out what it is more.*" When we asked her what she meant by *more*, she explained: "*How I was trying to figure out what leaves that tree had. I wouldn't have looked really close at the leaves before.*"

In addition to drawing their attention to nature elements, the NC app sparked children's interest in learning more about nature. For instance, while showing us the photos he took during the post-intervention outdoor activity, one 10-year-old boy explained enthusiastically: "*I feel like I know more like that tree is called a pine tree, that tree has like this kind of shape. It makes me want to like show my friends, like, take a picture of this and show them, 'Oh you see that shape in the tree? That means it's this tree. See this bird of this? That's a song bird. This is a bird of prey.'*"

Children in the NC group expressed a desire to learn more about nature even after being outside. Children initiated conversations with their parents and siblings around different nature photos they had taken, and some even searched online to learn more about nature elements they observed. One 12-year-old boy explained: "*I would go on the computer or the phone and be like what's a cedar bark tree [referencing the app tree classification option]?*"

Photo app group. In contrast, the Photo app did not appear to draw children's attention to natural elements or motivate them to interact with nature. Instead of focusing on the specific details of a nature element (e.g., leaf type), their photos were more likely to be driven by a focus on the aesthetics of the photo composition (e.g. shape, color). For example, one 10-year-old girl was asked during the post-intervention outdoor activity: "*What are you normally thinking of when you take pictures?*" The girl explained "*Just how it looks, like that [points to a spider web near the building entrance]: I like how spider webs look. It captures the water droplets, it keeps it like that, it doesn't spread out, when it catches it like the ground, it doesn't disappear.*"

Children in this group mentioned taking photos for personal relevance like their backyard, pets, or selfies of themselves and their peers for fun. When asked to explain why he took the photos he did, one 9-year-old boy said: "*Anytime I wanted to see our frontyard without having to walk away from my show or my toys.*" He went on to show some of his photos and commented: "*I also really like this selfie by the beach…I think this one's funny.*"

Being IN Nature: Feeling Comfortable With Natural Elements

NatureCollections app group. Enjoying one's time in nature is one indication of feeling comfortable in nature. We therefore looked for evidence that children were engaging in nature-based activities that they found *fun and joyful*. Both the NC and Photo app children reported feeling happy and enjoying nature when they were outside with their app. Children in the NC app group reported being more excited and passionate about nature after using the app. One 9-year-old girl described her feelings about nature during the post-intervention activity interview: "*I'm more passionate about nature now, just by using the app and being outside more.*" Similarly, another 12-year-old girl explained her experience using the app: "*I also think it's easy and it works its goal of using technology to help you appreciate nature. I kind of noticed a trend in my audio recordings: at first, I was simply talking about what I took a photo of and why, and later when I was using the app I started talking more about how I feel about nature in general and why I took a photo in more detailed reasoning.*"

Beyond simply enjoying nature, children in the NC app group expressed *amazement and awe*, which appeared to heighten their connection to nature during their outdoor exploration with the app. One 10-year old boy explained his surprise upon learning that trees are living things: "*Before, I thought that trees were pretty boring cause they're just trees. But then when I started taking pictures with them, they're not just trees, they're actually living! So they're like us, but they're not moving around. They're staying put. They don't have faces, but they're alive and we have to take care of them... like trees are living things!*" Similarly, a 9-year-old girl expressed her wonder about nature while showing us a photo of close-up leaves: "*I think nature is really really fascinating, like skeletal leaves: those are really really cool.*"

Lastly, *interacting with animals* is another indication that children feel comfortable in nature. In our analysis, we found that children who used the NC app were more likely to describe interacting with wild animals. For example, one 9-year-old girl narrated the story behind a close-up photo she

took of baby birds: "*I took a photo of a bird, a bird and its mama and babies at my grandma's house. There's a mama bird nest. And so, my grandma tried to take care of it and told me to get water and I tried to get close to the birds. But sometimes it's weird when they open their mouths, the babies! Cause it's black and looks like a little hole.*"

Photo app group. Children who enjoyed using the Photo app told us that they liked photography, or that they took pictures of things that were personally meaningful to them. For example, one boy explained while showing us the photos he had taken: "*I like trees cause I can climb them. ... these are the trees I've climbed before.*" He also talked about liking how the trees looked at certain times of the day, for example, during sunset: "*I'm not sure what trees those are. [They are the] tallest trees in neighborhood. I like their colors [referring to the sunset lighting].*"

Unlike children in the NatureCollections group, children in the Photo app group did not exhibit evidence that the app facilitated their direct interaction with nature, and they did not express amazement related to nature elements. When we asked these children if the app helped them notice things differently in their surroundings, one 11-year-old girl said: "*I don't think so, it was the same before and after. I don't really pay attention to how much I notice and how much I don't.*" Although children in the Photo app group were often drawn to aesthetic qualities of their natural surroundings, this focus was not typically accompanied by an expressed interest in or enjoyment of nature. One 10-year-old girl explained: "*Sometimes I see something and think 'Oh, that's pretty,' but I'm never like 'I want to take a picture of that or get close.*"

DISCUSSION
In light of the critical role of nature exposure during childhood, researchers and educators are increasingly motivated to create nature-based experiences for children that promote nature exploration, curiosity, and direct engagement with natural elements. Nature kindergartens and school programs that focus on direct child-nature interactions have increased markedly in recent years. In the United States alone, such programs increased from around 25 programs in 2012 to more than 250 programs spanning 43 states in 2017 [16,54]. In this work, we explored the potential for using mobile technologies to encourage children to spend more time outside and engage directly with nature.

The primary contribution of this work is empirical evidence from an in-situ, three-week experimental deployment of the NatureCollections app, showing that the app significantly increased the time children spent in nature, compared to children in the Photo app group. Prior research has found that direct nature interaction and spending time in nature play a pivotal role in children's nature connectedness and willingness to perform pro-environmental behaviors during adulthood [18,21,36,38,51]. In this study, we observed key qualities of children's nature interactions suggesting that the NatureCollections app promotes and supports the development of children's abilities of Human-Nature Connection [18].

Our results showed that for children in the NatureCollections app group, the app succeeded in promoting child-driven exploration and attention to natural elements, in contrast to children in the Photo app group. Specifically, we observed evidence that, while using the NatureCollections app, children *directed their attention* to their natural surroundings, such as pointing to birds, bunnies and bugs, and they engaged in tactile interactions with nature elements, such as feeling tree trunks, reaching for tree leaves, and touching dirt. They also interacted with nature in a way that was *child-driven*, even seeking to extend their learning after their time in nature by engaging their parents in conversations about what they had seen and photographed with the app. These observed qualities of significant nature-based experiences in the NatureCollections app group supported children's *curiosity about nature*, one of the HNC abilities associated with *being IN nature* described in the Giusti et al. framework [18].

Children in the NatureCollections group also showed indicators of *feeling comfortable in nature*—another HNC-related ability associated with *being IN nature* [18]. Children in this group expressed being *happy, excited, and passionate* about nature after using the NatureCollections app during their outdoor experiences. Those experiences were often accompanied by a sense of *awe and amazement*. During our post-intervention outdoor activity, children who used the NatureCollections app recalled positive nature memories about their nature experiences as they showed us the photos they had taken during the study. Children also felt comfortable *interacting with wild life* while using the NC app, getting close to animals and bugs in order to photograph them. In contrast, the children in the Photo app group engaged considerably less with their natural surroundings, taking photos indiscriminately with no clear subject or purpose beyond the aesthetic composition of the photograph. Although these children showed excitement about being outdoors and engaged in play, these interactions rarely centered on direction interaction with nature elements.

Several features of the app contributed to these results. First, children's experiences with the app were highly child-directed experiences. Children could choose what to photograph, which collections to build, and which challenges to pursue. Features such as ""Add Details," "Classifications," and "More Information" also facilitated children's direct nature interactions and enjoyment of their time in nature. For example, in the process of making classification decisions for a nature element, children often expressed amazement and drew their attention to a natural element while making close observations of its details. Similarly, the "Add Details" feature of the app allowed children to reflect on their choices of what they had photographed and articulate in their own terms how to describe the nature element. When children engaged with

this feature, they showed curiosity and inspected the natural element closely, especially when attempting to classify it. After learning more about the different species using the "More Information" feature, several children reported feeling comfortable getting closer to a variety of natural elements, such as bugs and other animals, in order to photograph them. Children who used the NatureCollections app also engaged in conversations with peers and parents about the nature elements that they photographed.

LIMITATIONS AND FUTURE WORK

There are several limitations to the claims we can make from our data. We conducted this study with children and parents who were mostly from middle-to upper-class backgrounds. Although other demographic characteristics are reflective of the study location, our sample is not representative of the general population. Prior work has shown that geographic region, culture, and socio-economic status influence people's relationship to nature and their motivation to spend time outdoors [34,36]. This work suggests that users' experiences with NatureCollections might also vary systematically along these demographic dimensions. Future work could look at designing for the complex ecologies associated with children's lived experiences, for instance, by designing to include family members in children's nature explorations.

Another distinction to our sample is the fact that it took place in one of the greenest urban cities in the US, where spending time outdoors in nature is generally highly valued. Children living in other areas of the country may experience the NatureCollections app in quite a different way depending on their prior relationship with and experiences in nature. Future work could deploy the app in different geographic regions of the US to explore whether children engage with the app in systematically different ways [12].

Almost all of our participants in both app groups expressed feeling a burden from carrying the device while being outside. Our team's decision to design for mobile technologies was driven by their widespread and easy access for children, [70]. Future work can draw from the heads-up prior research [48,50] and explore other form factors, such as wearables, spectacles, and non-screen-based technologies that leverage cameras along with voice interfaces, projections, and sensors.

CONCLUSION

In the current work, we have shown how the design of the NatureCollections app supports children's increased time in nature—a critical factor to increasing children's connectedness to nature. The features of the app promote key qualities associated with significant nature-based experiences, which in turn supports the development of children's abilities to connect with nature. These features strike a balance between supporting child-directed exploration while also providing external scaffolding (e.g., supports for identifying a plant or bird). Although the app successfully harnesses the capabilities of mobile technologies, we believe that future work should leverage these insights and explore non-screen-based technologies that might be even more successful at connecting children to nature.

SELECTION AND PARTICIPATION OF CHILDREN

We recruited through university listservs, social media posts, and flyers at local libraries. Each child and their parent that agreed to participate in the study met with a researcher separately to go over the 3-week research study details and review the IRB polices. Children and their parents were told that their participation was voluntary and that could stop using the app or choose to withdraw from the study at any time. Written consent and assent were obtained from each parent (consent) and child (assent). Each family received a $25 gift-card after the first week and an additional $50 when completing the study interview at the end of the third week.

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