Chapter 14
Sociomaterial Configurations and Resources Supporting Observations in Outdoor Learning: Results from Multiple Iterations of the Tree Investigator Project

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Abstract Guided by a sociocultural framework that considers the intersection of people, tools, and settings, we describe research and development aims of a mobile app and the pedagogy supporting its use in outdoor learning. Our research investigates sociomaterial configurations that can influence youths' observational practices with tablet-mediated collaborative knowledge-building activities. Our work includes field tests with hundreds of learners and seven design-based research (DBR) iterations with 185 consented subjects. We report findings across these iterations of research, which are related to (1) the material conditions of the technology design and redevelopment and (2) the evolving theoretical framework focused on the concepts of scientific talk and practice. This chapter describes how we conducted our iterations of research leading to our trialogical approach to learning. As such, we describe how the materiality of the outdoor setting influenced our work and how various sociomaterial configuration for learning emerged based on our research findings. Implications for tablet-supported collaborative learning and technologically enhanced informal learning are drawn in the conclusion of this chapter.

Introduction

Our work builds from the sociocultural approach for education (Cole, 1998; Vygotsky, 1980) to understand how tools, people, and contexts come together when learning. More specifically, we draw upon theories of sociomateriality (Orlikowski, 2007) that posit that learning and meaning-making rely on

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technologies, places/spaces, and natural and designed objects present in everyday life—or in our case, people learning together with tablet computers in outdoor settings. This perspective is apt for research and development efforts with mobile computing for two reasons. First, one main goal of our work is to engage youths and families in the intellectual work of scientists; as shown by Latour and Woolgar (2013, 2nd ed.), the intellectual work of scientists relies on sociomaterial practice. Second, scholars in education have made the argument that not only are work environments relying on social and material interactions but so too are learning environments—understanding how learners come to understand a concept, for instance, is best accomplished with the tools used to learn that concept (Ivarsson, Schoultz, & Säljö, 2002). Within this chapter, we elucidate how we manifest sociomateriality in our research and development work. The first part of the chapter, we discuss how sociomateriality influenced our design across multiple iterations of research. In the second part of the chapter, we discuss how our data analysis moved from a dialogical to a trialogical perspective to fully illuminate the sociomateriality within learning interactions.

Research and Design Partnership

To accomplish our tablet-supported learning research and development work, we partnered with two outdoor learning centers, the Arboretum at Penn State and Shaver's Creek Environmental Center, to integrate tablet technology into youths' and families' science learning activities. Our work aimed to take a ubiquitous tool, a mobile phone or small computer tablet, and transform it into a learning resource that supported the creation of digital artifacts in the outdoors. Across our 6-year partnership, we designed learning experiences that met the rigors of the discipline of biology by engaging youths in collaborative sense-making around evidence they observed on nature trails. The trail-based learning activities needed to be educative and also fun—in order to reflect people's recreational goals for their out-of-school time. As such, we designed a mobile app and associated pedagogy for two related scenarios of use: (a) elementary-aged youth and their parents during family time (weekends, vacation days) and (b) 9–12-year-old children who signed up for a summer camp as part of their normal daycare or leisure activities. Both families and summer camp learners used the app during recreational time as they walked outdoor trails, exploring water and land habitats, and seeking serendipitous exposure to plants, animals, and nonliving features of the local ecosystem. We have used the Tree Investigator (T.I.) materials with over 400 youths and adults in developmental scenarios including youth attending a 1-day Arboretum fieldtrip, family visits to the Arboretum, and hundreds of summer camp children at Shaver's Creek and the Arboretum.

Design-Based Research Iterations

Our formal research findings are derived from a series of studies with 185 consented individuals across seven research iterations. DBR iterations 1–3 (Land & Zimmerman, 2015; Zimmerman et al., 2014) were focused on development; these iterations involved smaller numbers of learners and focused on fine-tuning the design of the T.I. mobile app to be suitable for informal educational uses. Iteration 4 (Zimmerman, Land, & Jung, 2016) and iteration 5 were the largest data collections; these iterations of T.I. focused on pedagogies exploring various configurations of sociomaterial support that could best influence science learning and youths' interests in science. From iteration 4 and beyond, the T.I. app included an augmented reality (AR) browser, digital photography, digital artifact creation, and on-the-fly annotations of learner-collected digital photographs. Iterations 6 and 7 worked with a smaller number of learners and were student-led dissertation efforts to bring new theoretical approaches to the T.I. materials. Iteration 6 focused on creating an imaginative narrative account featuring a squirrel in a comic-book-like format (Seely, 2015) and iteration 7 (Choi, Land, & Zimmerman, 2018) focused on integrating problem-solving techniques into informal learning experiences. This chapter discusses most fully iterations 1–5 but brings in the work of our colleagues from the last two iterations to consider how varying sociomaterial resources can influence learning (Table 14.1).

Within this chapter, we use our research and development efforts related to the Tree Investigators app and pedagogy to illustrate two ideas. First, we discuss how sociomateriality can inform and influence design efforts to support everyday

Table 14.1 The iterations of *Tree Investigators* app and pedagogy

	Focus	Learners
Iteration 1	Exploration of trees' life, reproductive, and season cycles.	Families in a garden
Iteration 2	Exploration of the tree life cycle with a photo-task for articulation and reflection	Families in a garden and forest
Iteration 3	Exploration of the tree life cycle with Augmented Reality scaffolds and photo-task for articulation and reflection; annotations	Children on forested trails
Iteration 4	Exploration of the tree life cycle with Augmented Reality scaffolds for photo-task and observational practices and collaborative annotations of digital photographs	Children on forested trails
Iteration 5	Exploration of the tree life cycle with Augmented Reality scaffolds for photo-task, annotations, and observational practices with additional support for peer discussions	Children on forested trails
Iteration 6	Integrating story-telling narratives into exploration of the tree life cycle; incorporated graphic/comic elements	Children in a garden and on forested trails
Iteration 7	Supporting problem-solving and leadership moves of children within an identification of the three life cycle task	Children on forested trails

technologically-enhanced learning in the outdoors. We illustrate our team's early focus on place-based learning, which evolved into a fuller consideration of multiple sociomaterial resources and configurations within science learning interactions. Second, we discuss how our sociocultural theoretical framework evolved from a dialogical approach centered on learning conversations to a trialogical framework that considers more fully the role of learner-created digital artifacts as conversational partners. The trialogical framework not only more fully elucidated the sociomateriality of technologically enhanced learning, but it also allowed for us to realize our focus on science practices related to observational inquiry, which rely on instrumental and social components. Sociomateriality's influence in our designs and analyses of learning are discussed in full below.

Adopting Sociomaterial Perspectives *When Designing for* Technologically Enhanced Learning

Our perspective (Zimmerman & Land, 2014) on designing for mobile computing started with place-based approaches (Gruenewald, 2003; Smith, 2002)—especially for science learning (Lim & Calabrese Barton, 2005; Semken, 2005). To this, we added findings from informal technologically enhanced learning (Hsi, 2003; Lyons, 2009) for supporting heads-up, engaged collaborative technologies for museum settings; and from AR (Dunleavy & Dede, 2014) to digitally add layers of resources or perspectives to an object that allow people to use and create digital content via a mobile device. We sought to augment the natural world by adding digital media that enables access to non-visible information such as scientific perspectives, databases, or tools for capturing and sharing data (e.g., Chen, Kao, & Sheu, 2003; Land & Zimmerman, 2015; Rogers & Price, 2008).

Designing an Augmented Reality and Digital Photography App

Our design focuses on the affordances of tablet computers and other small mobiles for outdoor settings. Key within our effort was the idea that the design of an app for the outdoors was not a simple task—we needed to do more than bring existing perspectives on school-based or museum-based designs (from indoor settings) to outdoor learning centers. The nature centers' unique context of people learning within the materiality of outdoor settings was, and is, a driving factor in our design considerations. Understanding the sociomateriality of the learning interactions is relevant to technologically enhanced learning because some materials, defined as objects, bodies, technologies and settings, afford and constrain different actions (Fenwick, 2014) within a learning setting. For instance, people's experience in the outdoors is a sensory experience—with sights, smells, sounds, and textures that influence learning.

Given our project's focus on observational practices, we assert that learners' sensory experiences must be attended to within our design work to support engagement in the practices of science inquiry. As such, we prompted learners to touch trees' trunks, to look carefully at seeds, and to listen for key species in the area. In iteration 1, a naturalist worked with the app to prompt learners to look deeply at trees. In iteration 2, more of the prompts were distributed to the app with a photo-creation task. In iteration 3, we designed two phases of activity where the naturalist (and app) structured youths' experiences and observations, and then during the second phase, learners worked more independently. Our research (Land & Zimmerman, 2015) comparing learners' talk in iteration 1–3, found that learners were able to notice and describe the plant species that they were observing to each other in similar patterns regardless of the app/naturalist configuration (between 46% and 52% of the talk in all three iterations was perceptual). We interpret this finding to mean that the sociomaterial configurations of the learners, place, T.I. app, naturalist, and materials did not matter greatly for supporting basic science observation practices; all configurations that we employed were able to support people to observe basic tree traits. We discuss how these confirmations supported conceptual and sense-making talk below, where differences were observed.

In iteration 6 (Seely, 2015), we added a new technological configuration: a non-human agent was introduced, Nutty the Squirrel in a revised T.I. comic-book version app that was intended for a younger audience (ages 5–9). The T.I. app used Nutty and his narrative to suggest that the youths look deeply at the environment to assist Nutty to learn about trees (in order to find acorns). Seely reported that, in contrast to earlier iterations of the app, substantially more instances of affective talk were observed, likely due to the combination of the younger age of the participants and the comic-strip narrative of the pedagogical agent Nutty, who elicited playfulness from the children. In iteration 6, changing the sociomaterial configuration of the experience to include a narrative and a likeable comic-strip agent, led to a new pattern of talk and interaction that exemplified enjoyment, interest, and surprise.

We also designed our app for use by people engaging with a dynamic, temporally changing setting—leaves change over a year's time for broadleaf trees, pinecones appear on pines in annual or biennial cycles, and seeds and fruits are available at various points during the growing season. Across all iterations, we found that the setting influenced sociomaterial interaction among learners and technology. Specifically, the setting was influenced by weather and climate, which was often an unanticipated force that needed to be attended to in our design work and on-the-fly pedagogical choices. For instance, while we could run the study in light rain (with waterproof cases), much to the delight of the children in our study, sometimes the available light and temperature played a role in what animals and plants were available. The flora, fauna, and abiotic aspects of the environmental setting interacted with the technology in a way that influenced the effectiveness of our designs. Given our focus on trees, we sometimes needed to move learners off the intended trail and instead, we moved to a new location under the trees' cover to use the tablets in rain. However, the technology was more sensitive to changes in the settings; for instance, batteries and touch-screen performance in cold weather and with learners' gloved hands, provided a difficult barrier to address. Consequently, we limited the timing of the outdoor education program to spring through fall in our northeastern USA climate based on setting-technology interactions. The setting-technology interactions' influence on learning also meant that a human guide (naturalist, camp counselor, or other adult) needed to adapt their pedagogy or assist learners in unexpected ways.

Our views on sociomaterial interactions include that the learners' bodies were a valued material resource in learning situations (Nespor, 2013). As learners moved their body through the outdoor space using the T.I app, they controlled their focus based on their own excitement and curiosity, rather than on the informal educators' view of what was interesting This learner-centered approach has been important in our work with families, where we found families linger longer in their outdoor exploration when the object of their inquiry is a child's discovery, rather than something that the naturalist or guide pointed out (Zimmerman, McClain, & Crowl, 2013). While the T.I. educative programs start with a naturalist posing the question: *How do trees grow in the forest?*, as the program continued, the naturalist ceded much of the teaching to the app. To understand how trees grow, the app included text that encouraged learners to use their bodies to differentiate between a sapling and a mature tree. For instance, because the T.I. app was built to be used by children and/or families with children 11 years and under, we used youths' body references for size ("a seedling will be sized below your hips"). Given these references to body-oriented measurements in the app, children estimated the size of small trees using their body as a point of size reference. The app included text that encouraged learners to touch trees with their hands to make an estimate of the tree trunks' circumference. The text in the app asked them to place both of their hands around the trunk of a tree at their chest height to determine if the tree was a sapling (hands can touch if clutching a trunk of the tree) or mature tree (hands cannot touch at chest height). Through these text prompts, the app acted as a coach or peer to suggest how the learners' body could be used to differentiate between stages of the trees' life cycle.

Pedagogical View of Integrating an App into Out-of-School Time Learning

In addition to addressing issues of sociomateriality in our app's technology design, we also considered sociomaterial resources in our pedagogy for out-of-school time to integrate apps into outdoor learning centers. In iterations 1–3, the pedagogy included the naturalist asking the learners to work in small groups with one computer tablet (an iPad with an app). In iterations 4–7, the teaching support included additional supports for learners, in addition to the iPad app. Adding a new material resource arose because, from analyses in iterations 1–3, we found that when looking on the trails in peer groups, the young learner with the tablet was likely to wander away from other youths; or the partners without the tablet were likely to wander away from the person holding the mobile computer. Given that the tablet computer held the primary learning supports, this resulted in an interaction where at least one member of every group was exploring without the sociomaterial mediation provided by the T.I. app's learning technology. In iterations 4–7, we add a sociomaterial configuration for learners that included an artifact to support peer-interaction and intellectual ownership for learners not holding the iPad. The T.I. app was identical for iterations 4–5 and 7; however, the sociomaterial configurations were varied by the research team. In the later iterations, each child who did not hold the iPad was given a small, laminated card that provided information (an abbreviated summary of what included in the app, so that they still had access to information included in the app if separated from their partner) and an additional *intellectual role*. This role included that they were to double-check and discuss with their partner the tree specimen selected to be representative of each life cycle stage; we called this the "fact checker" and "evidence confirmer" role. This role-taking was manifest in our data when the person holding the intellectual card asked the person taking a picture of a tree specimen with the iPad for confirmation that the specimen had the characteristics of the life cycle stage as outlined by the app. Our work has shown that this additional intellectual role, when added to our pedagogy, fostered longer, deeper conversations between pairs and additional discussion of evidence and tree traits than the groups that did not have the intellectual role card.

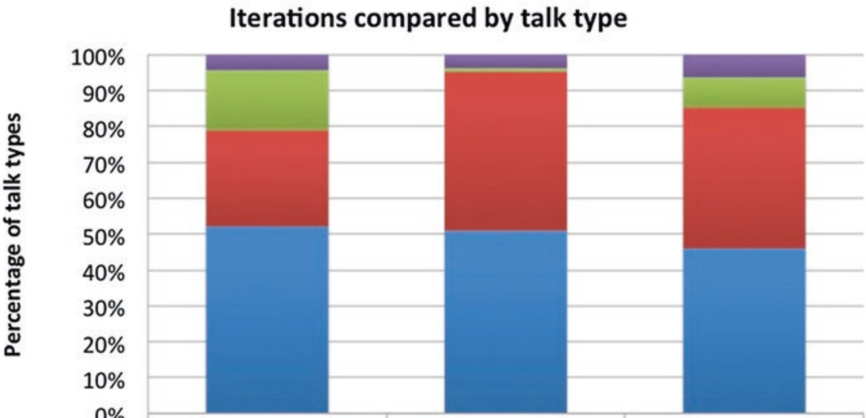
Adopting Sociomaterial Perspectives *When Analyzing* Technologically Enhanced Learning

Through our design iterations, as our technology evolved into a more complex, nuanced app to support science thinking in situ, we began to increasingly realize that our analysis needed to consider the influence of the app as a learning partner. Our original dialogical perspective from sociocultural theory allowed us to examine people's learning talk, but it did not fully account for the role of the app in supporting or hindering the learner. In the remainder of the chapter, we discuss how our research findings from our analyses of sociomaterial configurations influenced how we conceptualized tablet-supported learning.

In our research and development aims, we began our work with a sociocultural perspective on the importance of learning conversations (Allen, 2002; Leinhardt, Crowley, & Knutson, 2002), given the importance of sense-making talk (Bell, Lewenstein, Shouse, & Feder, 2009) in informal learning settings. These analyses of dialogue were important to our early work because the first three iterations of T.I. were focused on developing a flexible, collaborative mobile app that allowed learners to create, share, elaborate, and reflect on the plants (and animals) that they observed in their community gardens and nature trails. To do this work, we started our development efforts with an ethnographically inspired case study (Zimmerman et al., 2014). We started with families visiting an arboretum to understand what aspects of nature they wanted to share, what artifacts they wanted to create, what ideas they wanted to elaborate, and what science concepts they reflected upon.

From this work, we found evidence of the families discussing science topics together. Our analyses showed that the families discovered that there were science concepts in their community related to life cycles that families had questions about or in other words, wonderings that were unmet. We saw parents and children struggle to elaborate on some of what they were observing on plants, due to a lack of relevant scientifically-normative information. In iteration 2 (Zimmerman et al., 2014), we fine-tuned the app based on people's interests and on the struggles families faced. In iteration 3, we iteratively refined the photo-task to have scaffolds to make photo-documentation of the app more learner-centered, rather than naturalist-centered. Although these iterations were not designed to be experimental conditions, we (Land & Zimmerman, 2015) qualitatively compared the learners' talk from first three iterations in Fig. 14.1.

As stated above, all three versions of the app supported learners' ability to perceive and discuss basic observational features of the trees, as shown in the consistently high levels of perceptual talk across the iterations (Fig. 14.1). In iteration 1, we found the learners engaged in connecting talk (17%) and conceptual talk (27%) but we wanted to increase the conceptual talk to support engagement in explanation-building. In iteration 2 we added a conceptual organizer, and saw increased the conceptual talk (44%) but learners did not engage in the connecting talk needed to make sense of the content in light of their prior experiences (1%). In iteration 3 and



	1: species presentation	2: conceptual organizer	3: conceptual & annotation
Affective	4%	4%	6%
Connecting	17%	1%	8%
Conceptual	27%	44%	39%
Perceptual	52%	51%	46%

Fig. 14.1 The first three iterations of TI support learners' talk differentially, when analyzed with a learning talk framework from Allen (2002). Figure first appeared in Land & Zimmerman (2015)

beyond, the T.I. app included embedded prompts for discussion supports and collaborative annotation (within pairs or triads), building off prior work of collaborative annotation of video (Stevens & Martell, 2003). We found the collaborative annotation prompts were able to support learners' conceptual *and* connecting talk while on the nature trails (39% and 8% respectively). By having conceptual and connecting talk supported, the learners were able to make connections to theory, connect scientific objects and phenomenon on-site to prior experiences, and make inferences related to scientific concepts related to biology. Including both connecting talk and conceptual talk (Allen, 2002) are important in science learning because connecting talk represents sense-making and conceptual talk serves as a proxy for scientific thinking about the "big ideas" of biology needed for both further scientific study and civic engagement. We posit that given the number of groups walking through the forested areas, the app was able to provide just-in-time support to all learners whereas a naturalist could only work with one small group at a time.

A Trialogical Approach

As our work matured into iterations 3–5, we began to see how we needed a different theory — one that went beyond just considering the learners' conversations. Our data showed that the design of the technology influenced talk; to account for the sociomateriality of technology-enhanced learning by analyzing learning talk, we adopted a trialogical framework (Hakkarainen & Paavola, 2009) where we could analyze the role of the learner-created artifacts into the conversation. A trialogical approach considers the learners' artifacts as agentive in the learning conversations. This trialogical approach allowed us to analyze how the production of a photo-artifact influenced scientific sense-making in outdoor learning settings across sociomaterial configurations of learners, iPads, intellectual roles, and material resources. The trialogical perspective suggests that as people work together to create a knowledge artifact, the knowledge artifact is a both a learning process and a learning outcome (product) of the learners' interactions. In our research in out-of-school settings, we adopt the trialogical sociocultural perspective due to the importance of social meaning-making talk and creation in informal science learning (Bell et al., 2009).

Across the two iterations with the largest numbers of users (iterations 4 and 5), we compared two sociomaterial configurations. In iteration 4, children worked in dyads or triads with one iPad. In iteration 5, every child who did not have an iPad was given a small card that provided an additional intellectual role. In keeping with a design-based research perspective, the changes were derived from our analysis of the prior learning experiences as well as a desire to advance sociocultural theory that can support collaborative sense-making talk to support observation and explanation-building in youths' outofschool time.

Analyzing Science Learning Across the Groups

The trialogical framework allowed us to consider how 41 groups (consisting of 91 total children) engaged in the collaborative construction of digital photographic artifacts of tree life cycles at a nature center's summer camp. Overall the data from these two DBR iterations included: 91 matched preassesments and postassessments, video transcripts from 41 small group activities, and 41 learner-created, digital photographic artifacts. The small group work was transcribed and coded using a social sense-making scoring rubric to identify the extent to which learners collaboratively made accurate observations of trees and explained explicit connections to evidence or criteria that supported their identifications.

The unit of analysis was the sociomaterial interactions of each small group (rather than the individual child); the groups' scores represented the nature of collaborative sense-making while identifying five aspects of the tree lifecycle. Seven researchers coded one transcript together and then subsequently coded 16 of the 40 remaining small groups' transcripts separately on 12 possible pieces of evidence used to support claims about the identified stage of a tree's lifecycle, with each type of evidence being worth one point (12 points total possible). Interrater reliability was achieved at 90% accuracy for these 16 transcripts (representing 40% of the data). One researcher went ahead and coded the rest using the coding guide, which focused on the small groups' sociomaterial scientific practice of observation and coordinating evidence with explanations. In our coding guide, we include body interactions with plant materials, discourse, use of tools, and conversations with the youths' created artifact to realize the trialogical approach to learning.

Differences were shown in the sense-making scores between the two iterations, each featuring a different sociomaterial configuration. Our research found that the learners were able to discuss more observational evidence within scientific categories in iteration 4 to iteration 5 (iteration 5 had an extra tool and intellectual role for the child not holding the iPad). There was a significant difference in the scores for iteration 4 (averaged a score of 9) and iteration 5 (averaged a score of 10). Within the sociomaterial configuration of iteration 5 with the additional tool and role, small groups successfully discussed one additional piece of evidence (on average) in the 1-h program than the groups that did not have a specific role for the child not holding the iPad. We take our findings as a preliminary indication that during tablet-supported sense-making in science, fuller engagement in the argumentation and explanatory practices can be supported via adding a sense-making tool with an associated intellectual role to the child not holding the iPad tablet.

We found that utilizing the trialogical approach for a small group analysis allowed our team to take into account various sociomaterial resources and configurations for out-of-school time learning. We were able to determine how one sociomaterial configuration where each child who did not hold an iPad was given a small card with additional information and the intellectual role of "fact checker" and "evidence confirmer," led to teams discussing the tree life cycles with further detail and depth. We also found that learners coordinated their actions with the technology in order to accomplish the goals of the photo-task activity. For example, when one learner had the tablet and read the criteria aloud, the other partner made observations of the trees by identifying the evidence that matched to the tree onsite. In other cases, one partner would give confirmation to the partner to apply criteria to the tree. Most often, learners engaged in the activity as accountability partners to check and countercheck each other's observations and conclusions. In some episodes, when there were disagreements between the learners, one partner used the checklist as evidence to persuade the other partner why a certain specimen is not the specific tree type their team was looking for.

Analyzing Science Learning Within Each Group

To understand how these patterns the group analysis found manifest across the full dataset, we conducted a qualitative analysis of groups' meaning-making talk with a trialogical framework. The following episode with Richard and Ben exemplifies how the technology supported looking for evidence and fact-checking to develop a understanding of the observable traits of a tree's life cycle. The youths are trying to decide if the tree is a sapling combining observation of the setting and resources in the tool while engaging in a sense-making conversation:

Richard: Well, let's check. *[fact checker request]*
Ben: ((shakes tree's trunk)) Yeah, bendable. *[evidence confirmer]*
Ben: Yeah. ((reads from app's annotation tool)) Has a thin trunk that you cannot put your hands-
Richard: No, that you can.
Ben: But you can –
Richard: Yeah, it does, Trust me. *[evidence confirmer]*
Ben: Around chest height …
Richard: ((reads from app's annotation tool)) Does not have seeds or flowers.
Ben: ((looks at tree)) Does not have seeds or flowers on it. *[evidence confirmer]*
Richard: It doesn't. So, let me take it (photo).

At the start of this episode, Richard suggested that they check whether the tree is bendable (and therefore a sapling). Ben shook a tree to test to provide confirmation. Next, they had to come to a shared understanding of what a sapling was—whether you could or could not put your hands around the trunk at chest height. The two worked through this and realized that Ben misspoke "cannot" when he should have said "can." As this excerpt continues, the two learners exhibit similar patterns of behavior as before: checking the criteria and giving confirmation. In sum, the T.I. technology supported both Ben and Richard to engage in joint sense making. Ben who was holding the iPad became the content provider of the checklist, and Richard acted to test and confirm the criteria on the actual tree specimens. Ben and Richard are one example of how youths engaged with the sociomaterial resources to make sense of the life cycle of trees.

Implications

Given that we designed *Tree Investigators* to support families and children to engage in science practices related to trees, our work speaks to designing with sociomateriality perspectives in order to support science learning with mobile computers. Science education lends itself well to sociomateriality perspectives, given the conceptual, instrumental, and social nature of science teaching and learning (Duschl, 2008). We found that the blend of AR and mobile technologies, the trails and outdoor spaces, and natural and designed objects present in the nature centers could support learners sensemaking within and across various science practices (such as observation, explanation). Initially, we found (Zimmerman, Land, McClain, et al., 2015; Zimmerman, Land, Mohney, et al., 2015) that families engaged in high levels of describing and naming talk (Allen, 2002) around scientific observations; however, learners' conceptual (interpretive and explanatory) talk was less prevalent. In our later design iterations, we utilized the literature on scaffolding (Quintana et al., 2004; Xun & Land, 2004) to add more conceptual and participatory learning activities to our mobile AR experience. Learners increased their scientific vocabulary, noticed relevant features, increased conceptual talk, and accurately identified life cycle stages (Land & Zimmerman, 2015). In these later iterations, the use of a created digital artifact (a conceptual organizer made from pictures taken on-site at the nature center) was added as another sense-making tool—putting the youths in conversation with each other and the digital artifact as the youths made sense of important biological cycles present in their community, but previously unnoticed. Specifically, our work supports the inclusion of two digitals tools, digital photography and annotations, as scaffolds to support observations in the outdoors. In out-of-school time, video annotations shared between learners have shown to support learners (Stevens & Martell, 2003); our work adds the utility of annotations to photographs to support shared meaning-making in biology.

Conclusion: Theoretical Framework and Material Conditions

This chapter advances technologically enhanced outdoor science learning for out-of-school time with an empirical account of how the Tree Investigator app and its related pedagogy evolved over various research iterations within a design based research study. As our design approach evolved from a focus on placed-based education (with an original focus on learning in community spaces) to sociomaterial perspectives with a focus on place plus people's bodies, tools, material resources, and people, we were able to better support learning of biological concepts and sense-making, connecting talk. As our theoretical framework shifted from a dialogical (Allen, 2002; Leinhardt et al., 2002) to trialogical (Hakkarainen & Paavola, 2009) view to elucidate the sociomateriality of technologically enhanced learning, we were better able to focus on the scientific practice coordination of evidence with explanations.

Our work illustrates how theoretical frameworks and approaches to design, which operate at intersection of people, tools, and context, can evolve over time in design-based research projects.

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