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Toward a Framework for the Design of Interactive Technology for Nature Recreation

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ABSTRACT
Interactive technology has a complicated relationship with recreation in nature. Many people have praised, and many have lamented the impact of interactive technology on recreation in nature. Because nature recreation has important wellness benefits and interactive technology is likely to remain a part of nature recreation, there is a need to design interactive technology for nature recreation. Unfortunately, little generalized knowledge exists on how to design such technology. We create new intermediate design knowledge for interactive technology in nature recreation by drawing from others' work, our prior work, and specifically Borgmann and Verbeek's philosophies of technology. Our contribution is a framework based on a decomposition of engagement into nine facets related to engagement with place, time, and community. Four examples demonstrate the descriptive and generative power of the framework. This framework may enable the creation of interactive systems that complement rather than compete with nature recreation and may better preserve the wellness benefits of nature recreation.

KEYWORDS
Nature recreation; engagement; outdoors; wellbeing

1. Introduction

There is a growing body of evidence that recreation i.e., "activities, either active or passive, that take place during leisure as opposed to non-work-time" (Mercer, 2004). There is a growing body of evidence that recreation in nature generates wellness benefits for participants. These benefits include attention restoration (Kaplan, 1995; Kaplan & Kaplan, 1989), stress reduction (Ulrich et al., 1991), increased physical activity (Pietilä et al., 2015), and improved general wellbeing (Kauppi et al., 2018). By nature recreation, we mean recreation that takes place in settings where natural processes or depictions of natural processes dominate the experience. Borrowing from the definition of wilderness in the United States Wilderness Preservation Act of 1964 (U.S. Congress, 1964) where natural processes are processes that are not initiated by or carried out by people. For example, tree leaves turning red in autumn is a natural process but building a suspension bridge over a river is not.

Non-digital technology has affected the nature recreation experience for many decades. For example, synthetic fabrics for clothing and strong lightweight materials like aluminum for walking sticks and ski poles have created new ways for people to experience nature recreation. However, the introduction of technology to nature recreation has not been without controversy. For example, the unmanaged proliferation of automobiles into natural settings for recreation during the 1940s led to a degradation of natural areas and an entirely new approach to managing nature recreation including the concept of protected wilderness (Sutter, 2005) and the now ubiquitous organized campground loop for car-camping (Young, 2017).

Interactive technologies are now part of nature recreation experiences for many users, and like automobile use in the early days of automobile-enabled nature recreation, are also reshaping the experience with mixed results. For example, hikers carry mobile phones, cyclists use bike computers, runners wear smartwatch trackers, and trekkers use Virtual Reality (VR) to experience trails before traveling. Interactive technology can provide important benefits, such as supporting wayfinding, enabling emergency calls, and allowing activity tracking. However, using interactive technology in nature may detract from the wellness benefits generated by being in nature. Moreover, interactive technology use in nature might also affect people nearby; for example, there are reports of noise from drones negatively impacting hikers' nature experience (Clarke, 2023). Just as importantly, human-generated noise also impacts animals in nature (Barber et al., 2009–2010; Kok et al., 2023; Sordello et al., 2020)–including noise from drones (Mulero-Pázmány et al., 2017) and other air traffic (Alquezar & Macedo, 2019).

A simple way to avoid the pitfalls of interactive technology use during nature recreation is to leave it behind, however, it seems unlikely that many people will do this. Leaving devices behind has been advocated by many people, including hiking groups (e.g., ABC Radio Canberra, 2022), nature bloggers

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(Gatel, 2020; Thaik, 2020), and conservation groups (e.g., Ketcham, 2020). However, despite the simplicity of abstinence, the reality of today's digital lives is often more complicated. Many people *do* use headphones in parks, fly drones on beaches, use GPS wayfinders in forests, and carry mobile phones in a wide range of natural settings. Use and non-use of technology have been studied in general (Satchell & Dourish, 2009) and a more focused study of headphone use and non-use while hiking in the United States found well-reasoned rationales for either using or not using headphones while hiking (Anderson & Jones, n. d). Presumably, people choose to do these things because it improves their nature recreation experience. Furthermore, at least in the US, we know that nearly all hikers carry a mobile phone while hiking (Anderson et al., 2017; Lepp et al., 2023).

In contrast to interactive technology abstinence in nature recreation, we consider *interactive* nature recreation that intentionally involves interactive technology to create new kinds of nature recreation experiences. Design studies have emerged that began to explore the space of interactive nature recreation. These include an app that helps a hiker avoid other people on a trail network by scanning for Bluetooth signals (Posti et al., 2014), a system for adding the sound of forest rain to a walk in the city using headphones (McGill et al., 2020), and using virtual reality to recreate restorative nature experiences (Nukarinen et al., 2020). Others have contributed more general models of technology in nature (Coyne, 2014; Webber et al., 2023) but they do not address the possibilities of interactive nature recreation. Despite this growing body of work, there remains a lack of design knowledge for interactive nature recreation.

This article contributes a framework for interactive technology in interactive nature recreation based on viewing technology as a *mediator of engagement*. We decompose engagement during interactive nature recreation into engagement with three specific components: engagement with a place, engagement with a time, and engagement with a community. Based on our prior work in the study, design, and evaluation of technology in nature settings over the years, we further subdivide the three components into three facets each, resulting in nine facets that foreground different aspects of engagement in interactive nature recreation. These components and facets are summarized later in Figure 3. We derived the framework as a form of intermediate design knowledge (Höök & Löwgren, 2012), which exists between "universal laws" and specific results from single case studies. The framework is intended to increase design knowledge for interactive nature recreation. Our treatment of engagement draws from both the philosophy of technology and nature developed by Borgmann (Borgmann, 1987, 2010) and Verbeek's critique of Borgmann's writing (Verbeek, 2002). We further explain the philosophical foundation for our work in subsection 2.4.

2. Related work

2.1. Studies of HCI outdoors

Many papers have included studies of individual systems in the outdoors in different application contexts (Jones et al., 2022). We include several here that contribute to understanding IT in interactive nature recreation. The need for a general framework to organize ideas related to design for engagement with nature emerges from the set of ideas found in this collection of studies.

Outdoor HCI studies have involved drones (Mueller & Muirhead, 2015; Jones et al., 2016; Knierim et al., 2018), large format screens installed in fixed nature locations (Luusua et al., 2015; Taylor et al., 2018), and physical objects endowed with interactive computing (Lagerström et al., 2014; Ofer et al., 2019). Outdoor HCI studies have also involved different input modalities including gestures (Ackad et al., 2016; Jane et al., 2017; Parker et al., 2020) and voice (Pearson et al., 2019; Robinson et al., 2018; Zheng et al., 2015). Many output modalities have also been explored including sound (Hazzard et al., 2015; van Renswouw et al., 2021; Montuwy et al., 2018), electrical muscle stimulation (EMS) (Wiehr et al., 2017), and visual cues (Knierim et al., 2018; Mahadevan et al., 2018). Augmented (AR) and Virtual Reality (VR) systems have also been studied outdoors (Miksik et al., 2015; Schneider et al., 2023; Singh et al., 2021). These prior works suggest that the set of technologies in the design space for interactive nature recreation is large and diverse.

Other prior work suggests that different aspects of engagement could be manipulated by interactive technology. For example, Colley's system for skiing in "blended virtuality" replaces the skier's view of a ski slope with a purely virtual world that loosely corresponds to the actual world in which the skier is moving (Colley et al., 2015), thus suggesting that one place can be substituted for another. Renswouw supports engagement with a modified nature-centric version of reality by adding nature sounds to urban jogging sessions (van Renswouw et al., 2021). Kunetsov's visualization system assigns different colors to balloons to reflect air quality (Kuznetsov et al., 2011), enabling engagement with information about places humans would otherwise find difficult to sense. Hsu's reporting system for tracking smells in a city, including natural smells (Hsu et al., 2020), supports engagement through smell. Schaefer, Tatar, and Harrison's GPS-based system re-constructs place in a landscape with deep historical significance by enabling noticing and remembering related to that history (Schaefer et al., 2010), thus suggesting that signifiers of the past can be part of engaging with a place.

Interactive technology can also manipulate engagement with other people outdoors. Posti's "Hobbit" system supports hikes to disengage from people on a hiking trail network by predicting and detecting other hikers and then providing routes and notifications to help the user avoid them (Posti et al., 2014). This system supports engaging with a place while disengaging from people in that place. Heshmet et al. (2018), Chua et al. (2017), and Jones et al. (2016) created systems for changing how people engage with nature by enabling them to engage with people who are not present using a telepresence robot.

2.2. HCI in nature

A smaller body of work describes the role of HCI in nature more broadly. These works explore HCI in nature both in the context of a single study and in broader more conceptual contexts. We see engagement as a shared concept across this body of work and this inspires us to leverage engagement as a unifying theme.

For example, Coyne's "Nature vs. Smartphones" discusses the emerging (at the time) relationship between mobile computing and the experience of being in nature (Coyne, 2014). The article draws on Borgmann's concept of engagement and follows Borgmann's connection to Heidegger's phenomenology by discussing the role "things," or devices, play in reducing engagement with place, time, and a community. Coyne "buy[s] this argument" about things and their impact on engagement in nature and goes on to add that "one important function for high-tech devices is to disturb and bring into relief" elements of the experience of being in nature. Like Coyne, we also draw from Borgmann's writing. However, we focus on mediating engagement with nature during recreation rather than contemplating a generalized notion of disturbing and bringing into relief the experience of simply being in nature.

Häkkilä et al. organized a series of workshops on "unobtrusive user experiences with technology and nature" (Häkkilä et al., 2016, 2017). Bodker's position paper in the 2017 workshop involved Borgmann's focal things and practices in nature and emphasized the importance of context (Bødker, 2017). In the article, Bodker reflects on the shifting role of a smartphone as it transitions from a commodity in an urban context to a focal thing in a wilderness setting.

Overall, this workshop series culminated in a set of emerging themes generated by reflecting on work presented and discussed at these workshops (Häkkilä et al., 2018). The two workshops were meant to build a research community that investigates "the potential ways that digital technology and interaction design can support users' engagement with nature" (Häkkilä et al., 2018). The focus in these workshops was an *unobtrusive* approach in which technology remains largely in the background. Similarly, our work is meant to explore potential ways that interactive technology can change users' engagement with nature during recreation. But we see a larger design space that is not limited to (but includes) unobtrusive interventions.

Häkkilä et al. organized a series of workshops on "unobtrusive user experiences with technology and nature" (Häkkilä et al., 2016, 2017) culminating with a set of emerging themes generated by reflecting on work presented and discussed at these workshops (Häkkilä et al., 2018). The focus in these workshops was on an *unobtrusive* approach in which technology remains largely in the background. Similarly, our work is meant to explore potential ways that interactive technology can change users' engagement with nature during recreation. But we see a larger design space that is not limited to (but includes) unobtrusive interventions.

We also learned from prior work by Vella et al. involving human-nature relationships in inner cities (Rodgers et al., 2022; Vella, Dema, et al., 2021; Vella et al., 2024). Vella et al. argue for the need of human-nature engagement among children in inner city settings through the use of technology by co-designing interactive devices with children (Vella, Ploderer, et al., 2021). For example, the design of the "ambient Birdhouse" (Vella et al., 2022) aimed to create an environment that overcomes the negative effect of a sedentary lifestyle within an urban environment. Vella et al. also worked with adults to support human-nature interaction. This resulted in nature data (Vella et al., 2022, 2024) collections to ensure that humans notice and pay attention to fauna within the urban environment. This work highlights the importance of nature recreation and suggests different ways of creating engagement with nature in urban settings. Our work however, involves mediating engagement with nature during recreational trips to natural settings rather than during daily life in an urban setting.

McClain and Zimmerman highlight how technology can facilitate children's interaction with nature outside the classroom (McClain & Zimmerman, 2016). This is achieved through tools like the e-trail guide, an application on an iBook, which enhances children's sensory coordination and engagement with nature. The authors categorize engagement with nature into several types: task-based engagement, engagement through pointing (a social interaction), and engagement involving the investigation of natural objects. The concepts of this kind of engagement are encompassed within our framework. However, our work is intended for a recreational rather than an educational setting.

Based on the studies and models described so far, we see a gap in the understanding of how to design technology for interactive nature recreation specifically and it appears that engagement can play a key role in filling that gap. We propose new knowledge that might help designers create interactive technologies that support, rather than hinder, the fact that the user is recreating in nature. As part of that task, we draw upon concepts of engagement from outside of HCI and from the philosophy of technology.

2.3. More-than-human design

More-than-human design moves from human-centered design to consider impacts on animals, plants, and the entire planet–rather than just on humans. More-than-human design has been applied in several contexts including recent discussions specifically related to human-computer interaction (Coskun et al., 2022).

Wakkary's (2021) monograph on more-than-human design suggests that a "position of greater humility is necessary" when turning from a human-centered to a posthumanist understanding of how design impacts entangled relationships between humans and non-humans. Wakkery draws from post-phenomenological philosophies of technology in which technology mediates engagement with reality. From Wakkery, we learn to be humble and perhaps more considerate of how interactive technology design for nature recreation impacts non-humans who are also present in nature. Similar to Wakkery, we also build on technology as a mediator of engagement using a post-phenomenological approach (as explained in section 2.4). However, Wakkery's work does not directly address our driving question, which is to unpack how to design interactive technology to mediate engagement with nature during recreation.

Tironi et al. (2023) edited a book containing several works that explore a transition to design that is "more ethical" by focusing on "more-than-human existence." This approach to design aims for "new sustainable ways of relating to and being in the world." From this collection of work, we learn that interactive technology design for nature recreation can and should look at the other non-human inhabitants of the natural world as more than a backdrop for recreational activities. However, this work also does not address new forms of engagement that might be supported by interactive technology designed for nature recreation.

Heitlinger edited a volume on more-than-human design in the context of smart cities to "explore what it means to co-design with humans and non-humans" in order to create urban environments that "contribute to planetary health and wellbeing" (Heitlinger et al., 2024). Of note is Holland and Roudavski's chapter on participatory design "by trees, for birds, with humans" exploring how an expanded definition of community, which includes more than human lifeforms, can address environmental crises (Holland & Roudavski, 2024). From this collection of essays, we see that human engagement with nature in urban settings can be re-imagined to support the wellbeing of all involved. However, this work does not directly address how to design interactive technology that supports engagement with nature when humans temporarily leave the city for recreation in natural settings.

Others also explore more-than-human design in the context of engagement with nature in an urban setting. Smith reflects on two projects involving urban informatics to "promote new forms of cohabitation" between people and animals that "sees animals as part of the urban landscape" (Smith et al., 2017). Tomitsch et al. propose personas for non-humans in a "middle-out" design approach to form a coalition of voices that "speak on behalf of non-human species that are impacted by design decisions" in smart city projects (Tomitsch et al., 2021). Poikolainen et al. suggest noticing as a way to combine "human experiences and the needs of the environment" in the context of an urban garden (Poikolainen Rosén et al., 2022). From these projects, we learn that engagement with nature can be foregrounded not just in nature but also in cities in the context of people who live in the city. However, this work does not address how to design for engagement in the context of temporary visits to natural settings for recreation in which a person travels to a place where natural processes dominate but then eventually returns home.

Cabrera et al. present an inquiry into "other-than-human dataflows" in several different forests with the intent to "rearrange relationships" among entities involved with the forest such as "scientists, citizens, city officials, sensors, environmental data, climate change, trees, and other nonhuman species" (Botero Cabrera et al., 2022). From this work, we learn that data collected in the forest can be digested in multiple ways by different entities and that this should take into account the interests of nonhuman species. However, this work does not inform the design of interactive technology for mediating different human recreational experiences in or related to the forest itself.

2.4. Philosophical foundations

Borgmann frames technology as an entity that reduces engagement with reality and specifically reduces engagement with nature (Borgmann, 1987). Borgmann argues that technology reduces engagement by both reducing exertion and reducing meaning. Borgmann's writing is at times couched in the context of the American West in which "wilderness" is a specific kind of natural place that is (managed so that it appears to be) unaffected by human intervention. Borgmann writes that "it [technology] keeps wilderness at bay when … it insulates us from the engagement with the many dimensions and features of the land, as it does through rides in jet boats or helicopters" (Borgmann, 1987). In Borgmann's example, riding in a helicopter over a forest reduces engagement with nature by reducing the effort needed to traverse the forest and by reducing the meaning that might have been found by experiencing the sights, sounds, and smells of the forest. Borgmann further argues that technology reduces engagement with context and once context is removed, experiences become interchangeable commodities (Borgmann, 2010). We agree with the importance of engagement with context in interactive nature recreation. But unlike Borgmann, we see interactive technology as a way to create new forms of engagement with context. We believe these new forms of engagement are worth pursuing and understanding. We have adapted Borgmann's decomposition of engagement into engagement with the context of place, time, and community because we believe this decomposition operationalizes the otherwise abstract concept of engagement with context.

We find that casting technology *solely* as a *reducer* of engagement is too narrow. We agree with Verbeek (2002) who writes that Borgmann "only shows one aspect of the implications of technology for engagement with reality" and by so doing "neglects the ways technology can evoke new forms of engagement" (Verbeek, 2002). Looking at technology as a source of "new forms of engagement" is an expression of the post-phenomenological philosophy of technology that frames technology "in terms of mediation" of reality rather than "in terms of alienation" from reality (Rosenberger & Verbeek, 2015). In "entanglement HCI," Frauenberger (2020) argues that technology plays an active role in mediating engagement between humans and their environment. This reaffirms the post-phenomenological position that human experiences of the world are mediated by technology. Frauenberger (2020) re-emphasized Verbeek's (2015) argument that "designing interactions with technologies" moves "towards designing human relationships with their world." We draw from this position to strengthen our framework of engagement in the sense that we are designing toward creating human relationships *with nature* in the sense of creating recreational experiences in nature. We contribute to Verbeek's aspiration toward "developing responsible technological mediation" by arguing for carefully designed forms of mediation. This is a step away from design that "defend[s] human autonomy" against technology. But our work has some key differences. First, our work does not defend autonomy in general, we defend autonomy narrowly within recreational engagement with nature and leave other aspects for other work. Second, while ethics matter, we aren't explicitly focused on ethical issues. However, we will discuss the ethical implications of our work later. Instead, we are focused on preserving the wellness benefits of time in nature given inevitable technological mediation.

We decompose engagement with nature into engagement with a place, a time, and community. This follows Borgmann's (2010) application of Thompson's (2006) contexts of engagement for reasoning about the commodification of things. Decomposing engagement with a thing into engagement with a place, a time, and a community allows us to be more precise about what it means to engage with a thing. Borgmann argues that detaching a thing from contexts of place, time, and community reduces engagement with a thing. We apply this decomposition to because, we argue, the experience of being in nature is defined by engagement with a place, a time, and a community. We also believe that this decomposition has utility when designing interactive systems.

A "place" is a location that has been assigned a meaning. This use of place, versus space, is grounded in Tuan's concept of space and place (Tuan, 1978). The meaning assigned to a place varies from person to person and is influenced not only by the intent of the person but also by the topography, animals, and plants found in a location. For example, a person looking for a spot to have a pleasant picnic might assign a different meaning to a clearing in a mountain forest that affords a view of distant peaks than they would to a densely vegetated jungle containing many flying insects in which it is difficult to see more than 3 meters in any direction. Finally, it is important to realize that the meaning that a person assigns to a location may be very different from the meaning of that location for plants and animals that occupy that location.

A "time" is a specific point in time or a period of time. Engagement with time includes engagement with time-varying conditions as they exist at one point in time or over a period of time. In nature, time-varying conditions exist on many scales ranging from a few seconds to centuries. Time-varying conditions that impact nature recreation include the weather, animal migration patterns, and plant growth cycles. Weather conditions, for example, can have a significant impact on the experience of being in nature: walking through a broad desert canyon wash on a hot dry sunny afternoon is different than walking through the same canyon on a rainy day with flash flooding.

"Community" is broadly defined to include both a group of people with similar interests as well as a population of various species in a specific location. This broader view of community emphasizes the important role of plants and animals in defining the experience of being in nature. Engagement with community in nature includes engagement with other people such as companions and strangers, as well as engagement with other living things such as plants and animals. For example, kayaking through a swamp involves engaging with the community of animals and plants that inhabit the swamp such as alligators, egrets, cypress, and mosquitoes.

3. Methods

Our methodological approach to developing the framework was multifaceted and iterative. We break our methods into four steps: literature review, reflective discussions, design sessions with students, and reflection in nature.

3.1. Literature review

We studied the review by Jones et al. (2022) comprising 101 studies of HCI in outdoor settings to learn from what others have written about interactive nature recreation. In that collection, only 8 took place in nature areas. Of the 8 studies that took place in nature, only 5 involved recreation (Colley et al., 2015; Desjardins et al., 2014; Fedosov & Langheinrich, 2015; Kim et al., 2017; Pedica et al., 2021). Based on this analysis, we determined that design for interactive nature recreation was an emerging subtopic, intermediate design knowledge was needed, and that drawing from both this set of systems and more general models would be important.

To find more general models that might inform design for interactive nature recreation, we engaged extensively with the works of Borgmann (1987, 2010, 2017) and attention restoration theory of the Kaplans (Berman et al., 2012; Kaplan, 1995; Kaplan & Kaplan, 1989) We initially chose to read Borgman because his writing explores the relationship between technology and wilderness. Borgmann's concept of technology is more general than ours but seems to apply to interactive technology as well–even though the core ideas were developed before the advent of ubiquitous portable computing. Interactive technology as we know it today does appear specifically in later work (Borgmann, 2017). We chose to study the Kaplans' work because it is widely cited in the literature on the benefits of time in nature and is supported by a broad set of studies. Ulrich's model of stress recovery in nature (Ulrich et al., 1991) was an alternative but provides less detail on what it is about nature that reduces stress or restores attention.

Engagement as discussed by Borgmann emerged as a central unifying concept. The choice to organize the framework around engagement was guided by our own experience as designers and users of interactive technology for nature recreation. We also realized that the Kaplans' work describes environments, not activities or technologies, that produce attention restoration. Soft fascination is one characteristic of restorative environments that seemed related to engagement in the sense that poorly designed interactive technology could easily displace soft fascination. This realization further sharpened our focus on engagement.

3.2. Reflection

The framework presented here began to take shape during reflective discussions between the authors. We adopted

Borgmann's decomposition of engagement into engagement with a place, a time, and a community (Borgmann, 2010). This decomposition was also referenced in Coyne's discussion of nature versus smartphones (Coyne, 2014) and resonated with our review of prior systems for interactive nature recreation as well as our own work and experiences in the area.

Initially, we considered placing technology's impact on engagement on an axis of "increasing" or "decreasing" in engagement in these contexts. Verbeek also writes about technology as either increasing or decreasing engagement (Verbeek, 2002). This early axis-based concept is shown in the sketch on the left side of Figure 1 and circled in orange. While the text in these figures is too small to read, we have included them to document the way in which the framework took shape. Axes based on increasing or decreasing engagement were helpful but we saw a need to further unpack engagement to better bridge the gap between general knowledge and interaactive technologies. It seemed that these concepts were not yet understood enough to usefully make meaningful distinctions between degrees of engagement.

Subsequent reflection focused on bridging the gap by unpacking increasing or decreasing engagement into specific facets. A sketch of the framework from one of these sessions is shown on the right side of Figure 1. The three different highlights in the image illustrate facets related to place, time, and community. Yellow highlights show engagement with place, blue shows engagement with time, and green shows engagement with community. As before, the shape of the ideas highlighted in color is more important than the actual text in the diagram. Facets identified during this refinement process drew inspiration from the broad spectrum of individual HCI studies in nature discussed earlier as well as the authors' own experiences. These facets were modified slightly based on ongoing discussions.

3.3. Design sessions with students

Concurrent with these reflective discussions, one author tested the framework with 2 university students studying user experience in the context of computer science (one undergraduate and one graduate) over 14 weeks beginning in late April. Involving students in the refinement of a framework is similar to the approach taken in (Bruns et al., 2021; Mueller, Kari, et al., 2020; Mueller, Matjeka, et al., 2020; Mueller, Wang, et al., 2020; Mueller, Dwyer, et al., 2021; Mueller, Patibanda, et al., 2021; Mueller, Semertzidis, et al., 2023; Mueller, von Kaenel, et al., 2023; Mueller et al., 2021).

This collaboration involved twice-weekly meetings to discuss the framework and review design concepts. We initially applied the framework to 8 existing interactive technology designs from both research studies and commercial products. During these sessions, we tested the generality of the framework and refined methods for presenting the framework. We also began with a more concrete approach in which we attempted to fit interactive technology into a three-dimensional space described by axes of engagement with place, time, and community. We struggled to determine how different approaches to manipulating engagement fit in specific locations on the axes. This reinforced our decision to move toward further decomposition into facets.

During the second half of the 14-week period, we switched to a generative design phase that started with divergent thinking to create a set of concepts involving interactive technology for nature recreation. We switched to a convergent thinking step in which these ideas were

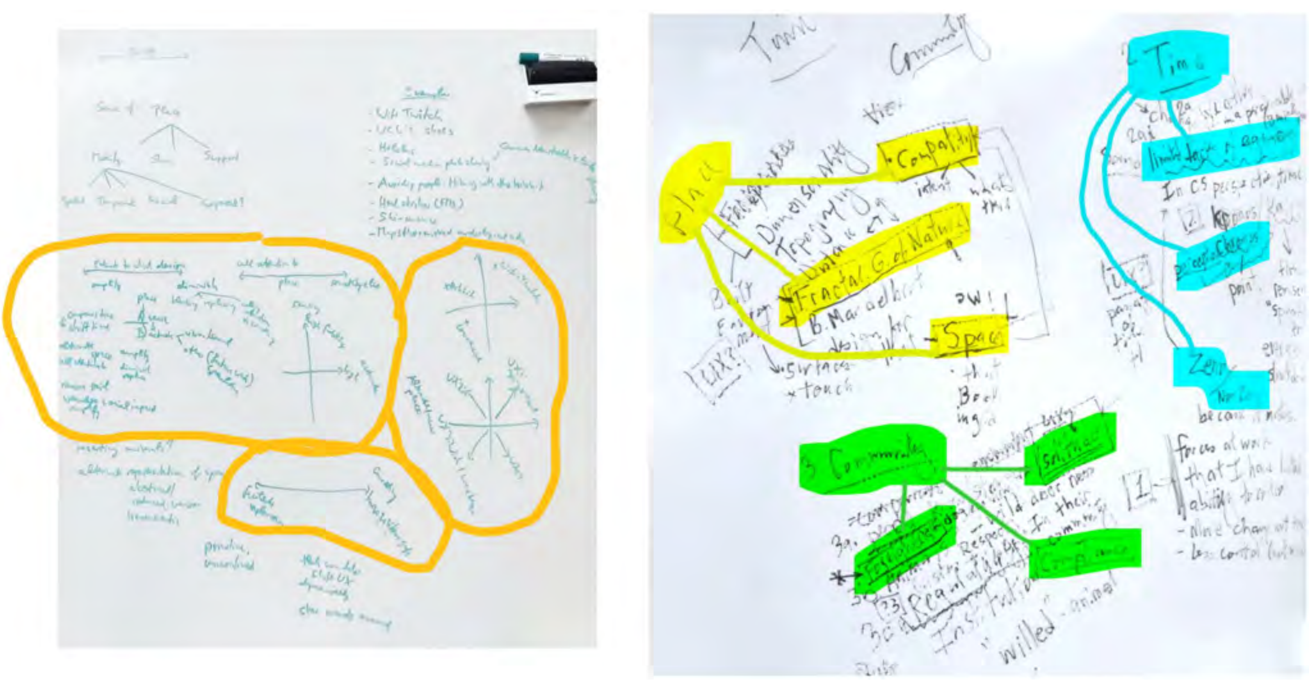

Figure 1. Snapshot of the evolution of the framework over time. The sketch on the left shows an early version based on axes of increasing and decreasing engagement (circled in orange). The sketch on the right shows a later model with place (highlighted in yellow), time (blue), and community (green) unpacked into three facets each. The facets in the final framework are based on and slightly different than the ones shown here. The sketch on the left was created in an author's lab space and the sketch on the right was created outdoors during a workshop at schloss dagstuhl, Germany. Colored highlighting was added for emphasis.

reduced to two final designs for prototype fabrication. We chose these designs based on how well they manipulated specific facets of engagement. These designs are discussed later in Section 5. One design was implemented as a low-fidelity prototype and evaluated on trails near a city. Interestingly, the prototype manipulated engagement differently than we expected.

3.4. Reflection in nature

Further refinement of specific facets occurred during periods of reflection as part of personal interactions with nature. These experiences in nature, particularly on trails in mountains near a university campus, deepened our understanding of engagement with a place, a time, and a community. Three photographs taken during these outdoor sessions are shown in Figure 2. Each of these photos captures a different refinement of one of the facets.

The photo on the left highlights the fractal geometry of a place as seen in the repeated profiles of the rock on the lower right and the ridge line in the upper left. Navigating these twisty and rocky mountain trails while looking at craggy mountains in the distance emphasized that engaging with a place means engaging with the geometry of the objects that place. For many places in nature, that geometry is better described by fractal rather than Euclidean shapes. Mandelbrot wrote: "Clouds are not spheres, mountains are not cones, coastlines are not circles, and bark is not smooth, nor does lightning travel in a straight line" (Mandelbrot, 1982). The place captured in this photograph sharpened our realization that engaging with fractal geometry can be a significant facet of engaging with a place in nature.

The middle photo highlights engagement with time at multiple scales ranging from fast-moving insects (unfortunately they moved too fast to be captured in this photograph), to the position of the sun throughout the morning, the annual progression of seasons throughout the year, and the geological evolution of the mountains over millennia. Creating the setting for this image requires the sun to be at the right point in the sky to create lens flare in the camera, and diffuse glow in the flower petals and shadows on the mountain in the background. Engaging with this moment in time caused us to realize that processes occurring across multiple time scales are one important facet of engaging with a time in nature.

The photo on the right shows regulations posted on a map at a hiking trailhead. These regulations illustrate engagement with a community through external expectations. The regulations are set by land managers and other community organizations. These regulations prohibit riding motorized vehicles and require keeping dogs on leashes. Other regulations can be inferred from land ownership which is shown on the map using colored boxes. One landowner, the Division of Wildlife Resources prohibits mountain bikes on trails during the winter to preserve winter habitat for elk. Other regulations are locally established social expectations such as rules for determining who should yield when two groups pass on a narrow trial. Reflecting on these regulations for this particular place emphasized that external expectations are an important facet of engaging with communities in nature.

4. A Framework for the design of technology in interactive nature recreation

Place, time and community are differentiating features of the recreational experience of being in nature. For example, walking through a forest (a place) during a rainstorm hour (a time) with friends (a community) is different than climbing a mountain (a place) on a sunny day (a time) with a professional guide (a community). Similarly, the presence of mosquitoes near a river (a community) creates a different experience than being near the same river in the presence of a large population of flying foxes (a community).

Figure 2. Photographs from outdoor reflections on engagement with place, time, and community on trails. Left: engagement with fractal geometry of a place. Center: engagement with a time on scales ranging from minutes to centuries. Right: engagement with external expectations set by a community are listed on the left side of a trail head map. Photographs by the authors.

Manipulating engagement with one element of the framework can overlap with engagement with other elements. For example, changing engagement with place using an augmented reality (AR) app on smartphone can also change how a person engages with time by showing how a place looks at a different time. It is also possible that the manipulation of one element conflicts with efforts to manipulate engagement with another. For example, efforts to decrease engagement with a community can conflict with efforts to increase engagement with a place when hikers are routed away from certain popular trails to avoid interacting with other people (similar to what is done in an asocial hiking app (Posti et al., 2014)).

We argue that technology modifies but does not always reduce engagement with place, time, and community in nature. We further argue that decomposing engagement with nature into place, time, and community has utility when designing interactive systems for use during nature recreation. Figure 3 shows the three components of the framework along with each facet In the presentation of each facet given below, we describe an activity that the reader can do to engage with that particular facet. These are intended to communicate the meaning of each facet through a first-person (Höök et al., 2018) engagement with nature recreation. We also include two examples that increase or decrease engagement with that facet.

4.1. A Place

Engagement with a place means engaging with a location in the context of a recreation experience.

4.1.1. Signifiers of the past

Natural places often contain signs or indicators that can trigger recollection of past events. In semiotics, a sign decomposes into the signifier and the signified (Barthes, 1977). In general, the signifier is the sign's physical form, and the signified is the meaning associated with the sign. In nature, the symbols often represent memories of previous events. Memories and recollections might be based on first-hand experience or indirect knowledge gained from someone else. The signifier might be an artifact from the human past, such as petroglyphs, pictograms, or ruined buildings, or it might be a change caused by a natural event, such as rock fall, windstorm damage, or avalanche debris.

4.1.1.1. Increase. A location-based mobile phone application shows a map of a place with highlights for certain signifiers and gives the history represented by each signifier to increase engagement with signifiers of the past.

4.1.1.2. Decrease. An AR application presents virtual signifiers for fictional stories grounded in a place to decrease engagement with actual signifiers of the real past in that place.

4.1.1.3. Experience. Visit an artifact left by humans in nature, such as a ruin or rock art. Contemplate what it might have been like to be in that place when the artifact was created.

4.1.2. Assigned meaning

Tuan's conceptualization of space and place says that "the difference between space and place is that a place has definition and meaning" (Tuan, 1978). Engaging with a place means engaging with one or more of the meanings that can be assigned to that place. One class of meanings that can be assigned to a space in nature includes meanings assigned based on compatibility with the intended recreational activity. Viewing natural spaces through their suitability for specific activities helps understand them based on their ability to facilitate these actions. People may perceive the same natural space differently, leading to varied interactions with it. For instance, a trail segment might be just a route to a destination for an experienced hiker, but for a young child, it could be a source of amazement and discovery.

4.1.2.1. Increase. An interactive system that trains a person to fish at a lake which is maintained for recreational fishing increases engagement with that assigned meaning.

4.1.2.2. Decrease. Playing an AR game in a place where play is not an assigned meaning, such as a cemetery, decreases engagement with other meanings assigned to the place.

4.1.2.3. Experience. Gather a group of friends to play a game of football in a forest. Consider how this activity reshapes the meaning of objects in that place, such as rocks or trees.

4.1.3. Fractal geometry

A fractal is a shape that has repeated self-similar structure down to arbitrarily small spatial scales. In contrast to the

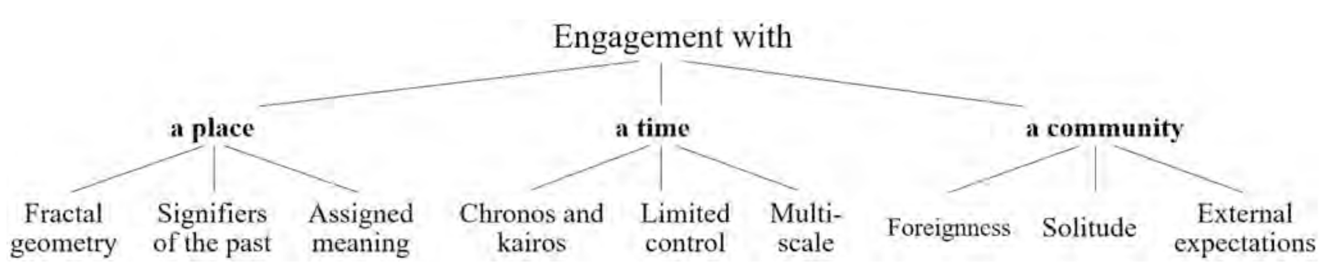

Figure 3. In the framework the role of technology as a mediator of engagement can be split into engagement with a place, a time, and a community. These three components are subdivided into nine facets that unpack engagement into manageable parts for design.

smooth shapes described by Euclidean geometry, fractal shapes are rough with curves, corners, and sharp edges. Smooth Euclidean shapes are often found in human-built objects and fractals are often found in nature. Mandelbrot, who coined the term "fractal," wrote about the fractal geometry of nature across different spatial scales (Mandelbrot, 1982). We find that engagement with a place in nature involves engagement with rough multi-scale fractal geometry in many forms. Engagement with fractals includes feeling the rough stones underfoot on a mountain path, examining the intricate details in exposed mudstone across many different spatial scales, and appreciating the branching structure of a tree. The fractal geometry of nature also influences movement in nature. For example, walking in a forest rarely involves moving in a straight line while walking in built environments often involves moving in a straight line.

4.1.3.1. Increase. An AI-powered mobile phone application that identifies different trees increases the perception of fractal geometry by presenting the smallest fractals of a recognized tree in an enlarged image, which would otherwise not be visible to the human eye.

4.1.3.2. Decrease. Imagine a fleet of small robots that removes the rocks from a trail as a person walks down the trail. A second fleet restores the rocks to their original position. This system decreases engagement with the fractal geometry of the trail surface

4.1.3.3. Experience. Measure a segment of the shoreline of a body of water using a 2-meter-long rod and then a 5-cm-long rod. When measuring, place the rod with both ends on the shoreline, then pick up one end and rotate it to the next point on the shoreline. Both the measurements and the journey to make the measurements will differ.

4.2. A Time

Engagement with a time means engaging with time-varying conditions as they exist at a specific point in or period of time.

4.2.1. Limited control

A time in nature recreation involves experiencing conditions over which we have limited control. These conditions include animal behavior, sun position, plant growth, and geomorphic processes. Not to mention the weather, which is perhaps the most impactful element beyond our control. Weather often necessitates changes in interactive nature recreation plans such as a windsurfer picking a location based on the wind speed and direction. Engaging with a time in nature means engaging with conditions largely beyond our control as they exist at that time.

4.2.1.1. Increase. An internet connection that blocks access to weather forecasts beginning 5 days before a planned nature outing increases engagement with limited control by decreasing the ability to predict future weather conditions.

4.2.1.2. Decrease. A climate control system that maintains a certain temperature in a 9 sq m plot of ground in a forest decreases engagement with limited control by providing additional control in a small area.

4.2.1.3. Experience. Pick a certain time to walk outside and walk at that time every day for two weeks, no matter the weather.

4.2.2. Multi-scale

In nature, things happen across a wide range of timescales, from fractions of a second to millions of years. For example, over several weeks in autumn, the leaves on many deciduous trees change colors, but a single leaf falls from the tree to the ground in seconds. Events across some timescales can be observed directly, while others cannot. For example, humans cannot directly observe the flapping of hummingbird wings. Geological and evolutionary processes that occur over hundreds of millions of years, which geology writer John McPhee calls "deep time" (McPhee, 1981), operate at timescales that are impossible to observe directly.

4.2.2.1. Increase. An installed display at a viewpoint that shows video recorded at that point (such as a surf webcam) six months ago increases engagement with multi-scale time by increasing perception of changes that occurred over the previous six months.

4.2.2.2. Decrease. Sensors mounted on a deciduous tree that detect changes in ambient air temperature and initiate the operation of heaters and coolers to keep the temperature constant to prevent the annual change of leaf colors decreases engagement with multi-scale time.

4.2.2.3. Experience. Watch a bird in flight and then look at a river flowing in its course. Visualize both the motion of the bird wing across a single flapping motion and then imagine the future course of the river in 100 or 1,000 years.

4.2.3. Chronos and Kairos

Nature recreation can facilitate moments when the flow of time seems to slow down or speed up. We can describe a point in time in concrete terms using hours, minutes, and seconds. This is the Chronos version of time. In nature, the first-person lived experience of time passing during a significant moment, which is called Kairos, can diverge from the measured Chronos version of time (Mueller & Young, 2018a). This experience can happen more frequently in nature recreation because clocks and precise schedules are often absent or ignored. Regarding Csíkszentmihályi's concept of flow, reaching a flow state in nature can create these Kairos moments when time seems to slow down (Jackson & Csikszentmihalyi, 1999; Csikszentmihalyi, 2014). Engaging with a time in nature often involves divergence between the perceived passage of time and the actual amount of time elapsed.

4.2.3.1. Increase. A hiking app that asks the user to enter how long they thought they hiked before revealing the duration increases engagement with the disparity between Chronos and Kairos experience of time.

4.2.3.2. Decrease. AR glasses that display the current time in the field of view and flash a bright light every 15 minutes in order to inform the user about remaining battery life will decrease engagement with the perceived disparity between Chronos and Kairos time.

4.2.3.3. Experience. Walk outside for exactly 30 minutes without using a watch to keep track of time. Note how the perceived passage of 30 minutes differs from the actual amount of time that passed.

4.3. A Community

Engagement with a community means engagement with a group of organisms, including other people, that are in the same place or that share some characteristics. Engagement with community invites designers to consider the impact of their design on non-human entities at a given place and time.

4.3.1. Foreignness

Communities in nature include communities of animals or people. Interactions between different communities generate feelings of foreignness. Human visitors to nature encounter foreignness on several levels. Orson Scott Card's science fiction universe includes a hierarchy of foreignness based on factors such as the ability to communicate and differences between species (Orson Scott Card, 1986) that we can adapt to foreignness encountered in nature. In Card's hierarchy, foreignness is more intense between species when communication is impossible. In nature, this corresponds to the foreignness people feel around animals with whom no communication is possible. Foreignness is reduced around animals with whom limited communication is possible, such as an elk (who respond to calls made by experienced hunters). Foreignness also occurs between people when communication is limited, and behaviors or intentions differ. For example, a group of French-speaking hikers who encounter a group of English-speaking motorcyclists on a forest trail will feel more foreign to each other than two groups of Spanish-speaking hikers who cross paths on a trail.

4.3.1.1. Increase. An information kiosk in a park that detects the languages spoken by visitors and renders text wrongly and in a different language increases foreignness.

4.3.1.2. Decrease. A smartphone app that pairs recognized bird calls with behaviors associated with those calls decreases foreignness by facilitating understanding of bird calls.

4.3.1.3. Experience. Spend time in a place that contains a large insect community, such as a bog. Interact with the insects and observe how they interact with each other and you.

4.3.2. Solitude

We can find solitude in nature. Solitude is engaging with community by avoiding community. In other words, solitude is intentional time spent alone or with a group separate from other people (Mueller & Young, 2017a, 2018b). Natural areas in the United States are defined by and categorized by their opportunities for solitude and the number of expected visitor encounters per day (Clark & Stankey, 1979; U.S. Congress, 1964). A day in the forest alone is different from a day in the forest with a group of friends, which is also different from a day in a forest crowded with strangers.

4.3.2.1. Increase. Automated trail signage that directs skiers to underused sections of a trail network based on the locations of other skiers increases engagement with solitude by reducing the frequency of encounters with other skiers.

4.3.2.2. Decrease. A live satellite video feed shared with a trusted friend that provides companionship during a river trip decreases solitude.

4.3.2.3. Experience. Find a blank spot on the map with no nearby roads, trails, or buildings. Travel to this place on foot and spend 15 minutes pondering this statement by Aldo Leopold: "To those devoid of imagination a blank place on the map is a useless waste; to others, the most valuable part" (Leopold, 1949).

4.3.3. External expectations

Communities create expectations for behavior in nature. These expectations are external because they are imposed on a person by a community. For example, several countries have explicit "freedom to roam" expectations even on private land codified in their law. The same freedom to roam does not exist for private property indoors. Other expectations arise directly from community values rather than formal laws. These expectations include the kind of rock climbing practiced at a location and what constitutes an acceptable ascent of a mountain peak. Engagement with community means engaging with these expectations even though the community may not be physically present.

4.3.3.1. Increase. An electrical muscle stimulation (EMS) system(such as proposed in prior HCI work (Patibanda, Hill, et al., 2023; Patibanda, Saini, et al., 2023; Patibanda et al., 2024), connected to calf muscles in both legs, that constricts muscles to prevent walking on fragile muddy trails increases engagement with external expectations by forcing compliance with community expectations around hiking on muddy trails.

4.3.3.2. Decrease. An interactive map that guides cyclists away from roads on private land that *do* allow public access decreases engagement with community expectations by avoiding open lands for cycling.

4.3.3.3. Experience. Use the internet to determine a piece of land's ownership status. Read all the regulations imposed by the owners. Travel through that land (if permitted) and follow all regulations–including those you might not have followed in the past.

5. Examples

We now illustrate the descriptive and generative power of the framework by presenting four examples of interactive technology in nature recreation.

After describing each system, we discuss the most relevant facets of that system. We give the facet's name followed by "descriptive," "generative," or both, in parentheses. This categorization indicates whether the framework was used to articulate the system's characteristics (descriptive), to inspire new versions or improvements of the system (generative), or both. Our use of specific systems to exemplify the use of the framework is similar to prior work (Eddy et al., 2023). and two of these examples result from class-based design exercises which is similar to the presentation of a framework in (Bruns et al., 2021).

5.1. Conversation Mute

Hiking is a form of nature recreation that involves walking in natural settings like forests or mountains for enjoyment. Some hikers prefer solitude, avoiding interactions with others on the trail. Conversation Mute creates an interactive nature recreation experience by decreasing engagement with other people on the trail, which decreases engagement with that community, in order to increase engagement with place and time. As depicted in Figure 4, the user wears a small microphone attached to their clothing and uses noise-canceling earbuds. In Figure 4, the microphone is the gray object clipped to the back of the hiker's cap. The system streams audio from the microphone to the earbuds unless it surpasses a certain volume level. If the audio is too loud, its amplitude is reduced and blended with pre-recorded environmental sounds. With the correct volume threshold, the device ensures that the wearer hears the ambient sounds in their surroundings, such as their footsteps, but does not hear other people's conversations while hiking on the trail.

Figure 4. "Conversation Mute" manipulates engagement with other people on a hiking trail by playing nature sounds in earbuds to drown out loud conversations on the trail. This picture shows testing of a low-fidelity prototype on a hiking trail. The microphone clipped to the cap records audio which is transmitted over a wire to a laptop in the backpack.

5.1.1. Place: Assigned meaning (describe)

Conversation Mute amplifies the meaning of place in nature by highlighting natural noises to reduce sound from human conversations. For many hikers, being in pristine nature means being physically and metaphorically away from other people, including their conversations. Loud conversations from other people can diminish this meaning. Conversation Mute also amplifies meaning by amplifying engagement with sounds from the nature setting by presenting those sounds through headphones. Based on our experience hiking with Conversation Mute, this small change focuses more on the variety, frequency, and relative distance of all the sounds present.

5.1.2. Time: Limited control (describe)

Conversation Mute provides some sense of control over the presence of other hikers on a trail. Hikers usually have little control over whether or not other people will travel on a given trail at a given time–especially for trails on public lands. This lack of control means that a hiker may encounter other conversations even when they do not want to. Conversation Mute provides some control by giving the wearer the choice of where to place the microphone to adjust the sensitivity, such as placing it near the foot versus on the shoulder, over how much of those conversations will be overheard.

5.1.3. Community: Solitude (describe)

Conversation Mute amplifies solitude by reducing the perception of other people's conversations on the trail. While it obviously will not afford the same experience as true isolation, the system is most useful for users who cannot control conditions on the trail and have no other alternative hiking locations. For people living in and walking in nature near highly urbanized areas, everyday access to solitude in nature is not feasible. By replacing conversations from passing hikers on the trail with natural sounds, the user has an illusion of solitude that may allow them to experience some of the elements of being alone in nature

5.1.4. Community: Foreignness (describe)

In our use of the system, Conversation Mute amplified foreignness between the user and other people on the trail. It was not easy to hear and communicate with passing hikers. This inability to communicate verbally encouraged us to avoid contact with other people. The inability to communicate verbally, and the increased opportunity for misinterpreted intentions, adds another element of foreignness to two groups otherwise engaged in the same activity.

5.1.5. Community: External expectations (describe)

Conversation mute defies social expectations about friendly greetings on hiking trails. We used Conversation Mute on trails where friendly greetings are expected as hikers pass each other. We ignored those expectations because we could not hear what other people said. We explicitly gave social cues that we were not interested in talking. For example, instead of making eye contact with an approaching hiker, we kept our eyes forward to avoid soliciting any greeting or conversation. From a passing hiker's perspective, our avoidant behavior or failure to respond to a greeting could be interpreted as odd or rude.

5.2. VirtuLab

VirtuLab is a 30 sq m rectangular room equipped with video projectors and an ambisonic sound system enabling a four-wall 360-degree virtual nature presentation paired with a soundscape (Figure 5). The system is used to bring nature environments (video and sound) indoors so that people can experience nature and its benefits. Suggesting that this form of engagement with virtual nature is, in some ways at least, similar to engagement with nature.

Forest bathing is a form of nature recreation that entails immersing oneself in a forest environment, prioritizing sensory engagement as a means to connect with nature and achieve relaxation. Note that forest bathing is "bathing" in the sense that one emerges in a refreshed state of mind and does not involve "bathing" in the sense of being immersed in water (such as in a lake in nature or the ocean; for this, see emerging work in WaterHCI (Clashing et al., 2022; Mueller et al., 2024).

VirtuLab manipulates engagement with a time, a place, and a community on two levels. The first and perhaps most obvious level is that VirtuLab replaces the place, time, and community found in a four-wall room with a place, time, and community recorded in nature. This manipulation of engagement aims to replace an indoor scene with a nature experience. Studies suggest that this kind of experience can impact wellbeing in similar ways to being in nature (Reese et al., 2022; Spano et al., 2023). Manipulation on this level touches on each of the facets of engagement discussed below.

The second level on which VirtuLab manipulates engagement with nature is that VirtuLab manipulates engagement with the recorded scene projected on the walls. This allows interaction designers to more easily manipulate engagement with a place, a time, and a community in ways that would otherwise be difficult or impossible to experience in nature.

5.2.1. Place: Fractal geometry (describe)

There is a striking contrast between the planar geometry of the room and the fractal geometry in the presented virtual nature. Presenting a virtual nature in the room replaces the aligned planar surfaces with rough fractals from nature such as trees, plants, and clouds. At the same time, VirtuLab reduces engagement with the fractal geometry of the recorded scene because the visual elements are seen in two dimensions rather than three.

5.2.2. Place: Signifiers of the past (describe)

By replacing the walls of a room with a scene from nature, VirtuLab replaces the signifiers found in the room with scenes from nature which may contain signifiers of the past. This can be especially powerful for remembering personal experiences in places that are similar to the place presented in VirtuLab.

5.2.3. Place: Assigned meaning (describe)

Presenting virtual nature in the room takes the space enclosed by the room and turns it into a place with several meanings. One meaning is that the room becomes a place for restoration. A more literal meaning is that the room becomes a place somewhere in nature. Engaging with that place in nature, even though it is a virtual representation of that place, may itself contain meaning assigned by the participant. For example, projecting a forest meadow in which the participant has camped with family in the past enables the participant to assign meaning to that place in terms of camping with family.

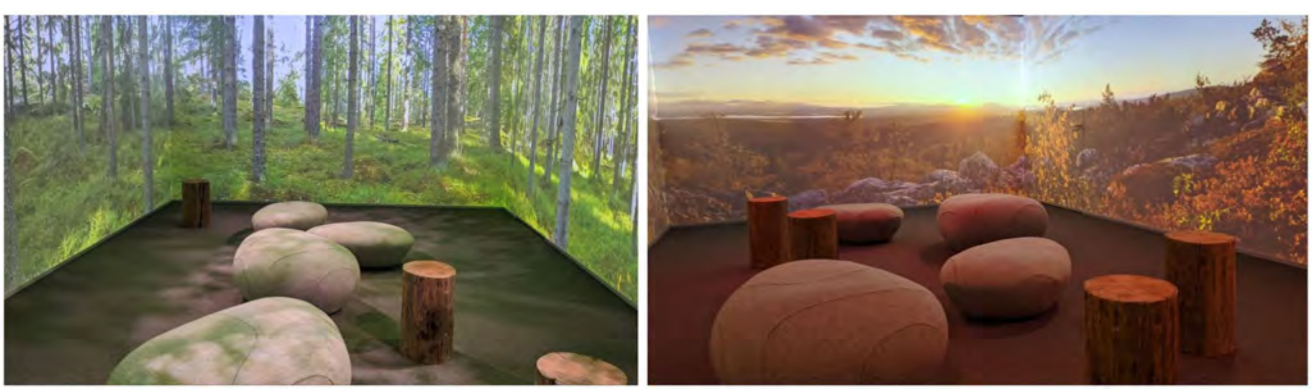

Figure 5. VirtuLab creates engagement with nature in a virtual setting in a room. The NatureHCI framework encompasses virtual engagement as well as physical engagement with nature.

5.2.4. Time: Chronos and Kairos (describe)

There is no clock in the VirtuLab room's wall, hence, it is possible to suppress the Chronos version of time. However, selecting a virtual nature presentation with a precise length (e.g., 15 minutes) and informing the participant of that length can strengthen the Chronos version of time. VirtuLab aims to create experiences that are more likely to facilitate the right moment (Kairos) in which to experience a flow state than is likely to happen in a (blank) room with four walls.

5.2.5. Time: Limited control (describe and generate)

VirtuLab can alter engagement with time by providing nearly complete control over the weather and season presented visually. The only limits are on what was captured in nature. VirtuLab also provides control over the air temperature felt in the room to a certain extent. These forms of control allow VirtuLab to create conditions that cannot be found in nature such as a high mountain snowstorm with an ambient air temperature of 21 °C.

5.2.6. Time: Multi-scale (generate)

VirtuLab could alter engagement with time by enabling one to perceive multi-scale natural events that cannot be observed directly in nature. Filming actual hummingbird wing flaps with a high-speed camera or shooting a time-lapse of a plant growing and then presenting those in VirtuLab could allow engaging with events over varying time scales, which would otherwise not be possible.

5.2.7. Community: Foreignness (generate)

The community around the participants in VirtuLab could be altered by creating nature engagement experiences with different levels of foreignness. This could be achieved by placing the participant into a foreign environment with different plant and animal kingdom species, such as a place the participant has never been to. The virtual environment could also include encounters with dangerous or rare animals safely.

5.2.8. Community: Solitude (describe)

VirtuLab manipulates engagement with solitude by artificially creating where it might not have existed in nature. Nearby sounds from road traffic, airplanes passing overhead, or passing visitors can be removed through AI-powered filters or added to a scene. Virtual nature presentations can be created so that they do not include people in the videos. This can require some effort to wait for the right conditions to occur or to manipulate conditions to create solitude (such as by artificially removing people in the videos through machine learning). Even if those conditions are infrequent in nature, they can be (re)played to create the impression that solitude is always present.

5.2.9. Community: External expectations (generate)

VirtuLab could allow the participant to act in ways that do not meet the code of conduct or external expectations in nature. Presenting a scene from a protected nature area that would otherwise be forbidden to access would allow bending the external expectations and make it possible to engage with that area (such as suggested in Greuter et al., 2022). A game-like virtual nature environment run in VirtuLab could present numerous possibilities to act against external expectations, such as planting trees in unlikely locations.

5.3. Wi-Fi Twinge

Wi-Fi Twinge (Liu et al., 2024) (Figure 6), allows a user to sense imperceptible environmental Wi-Fi signals through electrical muscle stimulation (EMS) that causes involuntary flexion of the fingers and wrist. Unlike an app on a mobile phone that allows one to sense Wi-Fi signals, Wi-Fi Twinge offers an embodied sense of nearby wireless signals on a pre-reflexive level: users feel a "twinge" if there is sufficient Wi-Fi signal.

One form of nature recreation involves being in a park in a city or on a university campus. For some visitors, the objective of being in a park is to get away from the constant flow of information received on a smartphone or smartwatch while other visitors may want to stay engaged with that flow of information. Wi-Fi coverage from wireless networks in nearby buildings may reach into parts of a nature park but park visitors can not directly sense areas of coverage. Wi-Fi Twinge creates an interactive nature recreation experience by communicating Wi-Fi network availability to the wearer. Awareness of Wi-Fi signals enables increased engagement with place by creating awareness of the spatial distribution of Wi-Fi network coverage in the park. This allows the wearer to move toward or away from areas with Wi-Fi coverage.

Wi-Fi Twinge continuously measures the total dBm value of the surrounding 2.4 GHz and 5 GHz Wi-Fi signal strengths. It categorizes the signal strengths into five levels: none, weak, normal, medium, and strong. Based on these, the system triggers a corresponding EMS stimulation wave pattern. The stimulation wave patterns were chosen based

Figure 6. Wi-Fi Twinge changes engagement with place, time, and community using electrical muscle stimulation that extends human perception to unseen Wi-Fi signals.

on a balance between the chance of muscle fatigue and ensuring that the different signal strength levels can be distinguished. Stronger signals result in higher stimulation frequencies and longer stimulation times.

A field study suggested that users who were initially occupying busy Wi-Fi areas, such as on a university campus, deliberately sought out nature settings, such as nearby parks, to reduce the "twinge," therefore facilitating visiting nature as a result of becoming more aware of the wireless signals around them in specific locations.

5.3.1. Place: Fractal geometry (describe)

Wi-Fi Twinge highlights the fractal geometry of nature by creating bodily responses to fractal-induced variations. In nature, the wireless signal interacts with the fractal geometry of a place to create uneven distribution patterns that vary significantly even over very short distances, such as taking a few steps (i.e., changing one's location in place) makes use of the roughness of the fractal geometry of the place to block or unblock Wi-Fi signals. In addition, Wi-Fi Twinge uses the fractal geometry of place to introduce new bodily responses to an environmental feature traditionally invisible to our senses, helping the wearer to become more aware of the relationship between their body and the place they are in.

5.3.2. Place: Assigned meaning (describe)

Wi-Fi Twinge assigns new meaning by facilitating a more bodily response (which can be associated with ill health, such as tremors) to the wireless signals in the particular space the wearer is located in. It extends the meaning of a place with wireless signals by highlighting to participants that where and how they locate themselves within their environment matters to their body (and possibly their health). Wearers may realize that natural settings with less Wi-Fi pollution are better places to be.

5.3.3. Time: Chronos and Kairos (describe)

Turning computer communication signals into a "felt" experience translates the signal into a human domain where Kairos becomes more prevalent. For example, a more actuated twinge is often attributed to a more "nervous" signal, as fast twinges are often associated with nervousness. As such, we can say that Wi-Fi Twinge facilitated experiencing a Chronos-focused technical feature into a Kairos-focused experience by turning sensed data into an embodied experience.

5.3.4. Time: Limited control (describe)

"Lack of control" is a key characteristic of Wi-Fi Twinge: the use of EMS has often been described as a unique experience of losing control (Knibbe et al., 2018; Patibanda et al., 2022). However, it is noticeable that people who move from urban to natural settings usually experience a reduced sense of control: they cannot protect themselves from the elements as much as they can in a city and are exposed to dangerous animals to a much larger extent than in cities. Though other people feel the opposite: they feel safer in nature than in the city. The Wi-Fi Twinge system inverses it: the user experiences a reduced sense of control over their body (at least their hand) as a result of locating themselves in nature. As such, the system does not highlight the lack of control in nature but increases the lack of control in urban environments.

5.3.5. Time: Multi-scale (describe and generate)

Wi-Fi Twinge engages with "multi-scale" through its mapping of the Wi-Fi signal to the EMS patterns. Although we mapped the signal strength, which has a similar scale to the EMS patterns, we could also envision mapping the frequency of the Wi-Fi signal (2.4 and 5 Ghz) to the EMS patterns: this would result in a much larger difference between the input and output, speaking to a truly multi-scale experience. With such a system, wearers could sense different Wi-Fi signals across their different bands.

5.3.6. Community: Foreignness (describe)

Wi-Fi Twinge amplifies foreignness through the EMS-induced twinging that is foreign to many people. In particular, bystanders could often notice the twinging (but might not say anything or comment on it as is often the case when noticing something foreign on another's body). If the use of Wi-Fi Twinge became widespread, the foreignness of such twinging would decrease. As such, Wi-Fi Twinge facilitated a feeling of foreignness with respect to one's own body.

5.3.7. Community: Solitude (describe)

Wi-Fi Twinge does not engage with solitude directly; however, several participants in a study of Wi-Fi Twinge reported that they sometimes felt socially awkward when their hands started to twinge in public places. Although they did not say so explicitly, we can envision that some might therefore try to seek less busy places where they are more alone. Such places are often found in the natural environments that our participants described as being sought out. As such, Wi-Fi Twinge facilitates seeking nature in order to find solitude, at least partially also due to the fact that these nature environments are less busy with other people and therefore reduce the potential for social awkwardness.

5.4. Dog's Eye View

Dog's Eye View is a design concept intended to amplify the meaning of a place as that place is seen by a dog. This is similar to prior work (Mueller, Lopes, et al., 2020) that allows seeing the world through the eyes of a child (Nishida et al., 2019). Dog's Eye View aims to amplify engagement with the community of dogs by amplifying foreignness. Dogs perceive a subset of colors compared to most people, and dogs have less visual acuity. Figure 7 shows a mountain scene as seen by a person on the left and as seen by a dog on the right. Note the lack of pink and red hues, desaturated greens, lack of detail, and shifted blue tones in the dog's eye view.

Figure 7. A mountain scene as viewed by a person (left) compared to seen by a dog (right). Dog's Eye view manipulates engagement with place and community by allowing a person to see what a dog sees.

For some hikers, a dog companion is an important part of walking through and experiencing nature. Interestingly, a dog's visual experience in nature is different than a person's because the dog's point of view is closer to the ground and dogs perceive a smaller range of colors than humans do. Dog's Eye View creates an interactive nature recreation experience by allowing a person to see a view more like a dog's view. Dog's Eye View increases engagement with the community by allowing a person to have an experience more similar to their canine companion. Dog's Eye View also manipulates engagement with place by creating a different perception of a given place.

The system uses a video camera paired with see-through head-worn display glasses. The camera is positioned on the belt so that the view in the glasses is akin to the view of the dog (assuming the dog's height is near the belt's height). The video from the camera feed is displayed in the glasses with colors altered to match a dog's visible color spectrum and acuity.

5.4.1. Place: Assigned meaning (describe)

The system alters how a viewer perceives the place by inviting the user to encounter their surroundings through a canine view. The user must reinterpret familiar locations within the distinct visual paradigm of a dog, potentially redefining the meaning attributed to these places. Objects or symbols that stood out visually in a human view may fade into the background in the dog's view and vice versa.

5.4.2. Place: Signifiers of the past (generate)

Dog's Eye View could be extended to highlight evidence of other dogs and animals who had previously visited the place. Dogs learn about other animals who have been in a place by smelling the scent of urine left by other animals. Dog's Eye View could be extended so that a person also acutely perceives the smell of urine left by other animals in the past. Using this increased awareness, the person can now engage with previously undetected signifiers of the past.

5.4.3. Community: Foreignness (describe)

Dog's Eye View can trigger a re-calibration of the human-dog relationship by manipulating the sense of foreignness. The system aims to amplify foreignness by allowing users to confront the dissimilarities in the visual sensory experience. This augmentation of foreignness can provoke reflection on how people and dogs interact with their surroundings and each other. Over time, as users acclimate to the dog's perspective, this heightened sense of foreignness may mature into a heightened sense of empathy and appreciation, ultimately reducing foreignness felt by a person and supporting a deeper connection between humans and dogs.

5.4.4. Community: Solitude (generate)

Dogs hear sounds at volumes and pitches that are undetectable by people. This allows dogs to hear animal sounds that people cannot. A person might experience silent solitude while a canine companion monitors sounds from nearby people or animals. Dog's Eye View could be extended to allow a person to hear what a dog hears. Expanding human perception of sound might decrease engagement with solitude as the person becomes aware of animals in the area that were previously undetectable.

6. Discussion

We have described an engagement-based framework for the design of interactive technology in nature recreation. We built on Borgmann's philosophy of technology in nature but take a post-phenomenological perspective in the sense that we see the role of interactive technology as modifying, rather than eliminating, engagement with nature. In this framework, interactive technology can increase or decrease engagement with specific aspects of place, time, and community in nature.

Webber et al. also used engagement as a central concept in their review of prior work involving HCI in nature (Webber et al., 2023). Our main contribution relative to this prior work is that we decompose engagement into three contexts and describe how to manipulate engagement with nature through those contexts. In terms of the typology of directness and distance established in prior work by Webber et al. (2023), our framework is intended for interactive technology that is used *in situ* and that mediates, abstracts, or simulates engagement. We focus on recreational settings while Webber et al. (2023) consider a much wider range of activities, including education and science.

Our work overlaps with certain aspects of "more-than-human" design that contemplates impacts of design on both human and non-human agents (Tironi et al., 2023; Wakkary, 2021). interactive technology that manipulates engagement for humans will likely have an impact on non-human entities. The "foreignness" aspect of the engagement framework explicitly includes engagement with other non-human entities. However, engagement with and impact on other non-human entities could also be considered as part of the facets of engagement with community. More-than-human design suggests that designers and users of interactive technology be more considerate and humbler about impacts on other entities in a natural setting. Ultimately, new forms of engagement with nature during recreation may result in deeper engagement with more-than-human agents and this may in turn lead to greater humility and consideration of human impacts on others.

6.1. Limitations and future work

A limitation of our work is that we have taken a Western approach to the concept of recreation in nature that is grounded in the Romantic Era belief that nature is a place of human renewal.[1] However, other human cultures conceptualize nature and nature recreation differently. Viewing nature and recreation through different cultural perspectives may lead to different ways of thinking about interactive technology in nature recreation. In order to avoid risking misstating other cultures' perspectives and their implications, we are reluctant to speculate on how different perspectives from specific cultures might impact interactive technology design for nature recreation but we do expect that there will be an impact. We invite deeper study of interactive technology in nature recreation in other cultures as future work by authors who are qualified to do so.

Another limitation is that we have not explicitly included people with disabilities in our framework. People with disabilities engage with nature in ways that are likely different than people without disabilities. Nevertheless, engagement with place, time, and community could be a reasonable starting point for the design of interactive technology for nature recreation for people with disabilities. For example, interactive technology designed for people who are deaf could approach engagement with solitude differently than for people who are hearing because noise pollution from a distant unseen highway more than 2 km away may have a different effect on perceived solitude. Additional work is needed to apply and most likely to revise the framework for people with disabilities.

The framework can guide design for people with diverse needs by foregrounding specific interactive technology to support specific forms of engagement. Engagement, viewed as an ability-neutral approach to nature recreation design, varies for different people with different abilities. Applying the framework to specific needs and abilities may prove useful for creating new nature recreation experiences for people with disabilities. Further work with specific populations is needed to identify how interactive technology can affect engagement for those populations. Involving people with disabilities in the design process will be a critical part of such work.

Despite the benefits of interactive technology for interactive nature recreation to better preserve the wellness benefits and help improve the wellness of individuals in nature, we acknowledge that our framework did not include non-human factors such as the environment. Also, design for interactive technology for interactive nature recreation may harm (Bedford et al., 2022) the environment because the production of interactive technology is a result of minerals mined from the environment and decompositions of the waste products occur within the environment. We have not yet explored the potential negative impacts of our systems on sustainability. This includes direct environmental impact resulting from using non-sustainable technologies, such as batteries, as well as indirect impacts resulting from over use or crowding. Prior HCI work has used "dark patterns" (Greenberg, Boring, et al., 2014) to investigate such dark sides of particular frameworks (Greenberg, Boring, et al., 2014). Future investigation of non-sustainability as a dark pattern may lead to important new insights.

A key limitation of our work is that we have not yet explored the generalization of our work through empirical work beyond the examples contained in this article. This approach appears in other work that proposes new intermediate design knowledge (Mueller et al., 2018; Mueller & Young, 2017a, 2017b; Mueller et al., 2011, 2014).

The framework serves as a starting point and should undergo further development in future endeavors. Several pathways can guide the framework's evolution. For example, we have only distinguished between increasing and decreasing facets of each component and have not yet examined other ways to manipulate specific facets, such as "eliminating" or "combining." Furthermore, additional facets could be considered, given that nature experiences are complex.

While we have validated the framework through our own applied work and the work of others, further validation is needed. This could include carrying out additional case studies involving published work. This could also include empirical research involving prototypes designed using the framework. This might be expanded to include workshops and design exercises involving a broad set of participants. By applying the framework to various interactive technologies in different nature recreation settings, we aim to gain a deeper understanding of how interactive technology can reshape how people engage with nature during recreation. These efforts will validate the generality and applicability of the framework.

7. Conclusion

The framework provides a more general understanding of designing interactive technology for interactive nature recreation. It has both descriptive and generative power, as shown by its application to four systems. Its components and facets promote discussions about these designs, offering a language to describe the integration of nature and interactive technology. Given the prevalence of interactive technology in outdoor recreation, understanding how interactive technology can enhance engagement may help to preserve the wellbeing benefits of nature recreation.

Note

1. For an introduction to the European Romantic Era concept of nature in general and as it applies to the construction wilderness as a concept in the United States (see Nash, 1967, chapter 4).

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