ABSTRACT

Title of Dissertation:	DESIGN CONSIDERATIONS FOR REMOTE EXPERT GUIDANCE USING EXTENDED REALITY IN SKILLED HOBBY SETTINGS
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As compact and lightweight extended reality (XR) devices become increasingly available, research is being reinvigorated in a number of areas. One such area for XR applications involves remote collaboration, where a remote expert can assist, train, or share skills or ideas with a local user to solve a real-world task. For example, researchers have looked into real-time expert assistance [1] and professional training of novices [2] in skilled physical activities such as field servicing and surgical training. Even as our understanding of XR for remote collaboration in professional settings advances, an area that has not been examined is how XR can support such expert-novice collaboration in skilled hobby activities (e.g., gardening, woodworking, and knitting). Metrics such as task accuracy or efficiency are often less important than in professional settings. Instead, other dimensions, such as social connectedness and emotional experience, may become central dimensions that inform system design.

In my dissertation, I examine how the XR environment can be designed to sup-

port the sharing of skills in hobby activities. I have selected gardening as a hobby activity to examine remote skill-sharing in XR between experts and novices. Like in other hobby activities, learning gardening practices remotely can involve asynchronous, text, or image/video-based communication on Facebook groups. While these may be helpful for individual questions, they do not capture the social, affective, and embodied dimensions of gaining expertise as a novice through situated learning in the garden. These dimensions can also be central to the experience of the activity [3–7]. In my work, I seek to understand how to design a social XR environment that captures these dimensions in ways that are acceptable and useful to intergenerational expert-novice gardener groups.

Through my dissertation work, I answer the following research questions:

- How do practitioners of a particular hobby exhibit sociality and what kinds of social interactions facilitate skill-sharing? What are some key opportunities for computer-supported collaborative work in this space? [8]

- What are practitioners' perceptions of using XR for skill-sharing? What are the important dimensions of the design space and design scenarios for social XR systems? [9]

- How do practitioners use different components of the activity space (e.g., tools or sensory stimuli) and their affordances to facilitate social connection? What context is essential to capture when reconstructing these objects virtually for remote interaction in XR (e.g., interactivity and realism)? [9, 10]

- What are some design considerations for XR to support accessible interactions that reflect the values and goals of an intergenerational group? [10, 11]

Design Considerations for Remote Expert Guidance Using Extended Reality in Skilled Hobby Settings

by

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List of Abbreviations

HCI	Human Computer Interaction
CSCW	Computer Supported Cooperative Work
DIY	Do-It-Yourself
XR	Extended Reality
AR	Augmented Reality
VR	Virtual Reality
MR	Mixed Reality
HMD	Head-Mounted Display
ADA	Americans with Disabilities Act of 1990
CAD	Computer Aided Design
WoZ	Wizard-of-Oz prototyping

Chapter 1: Introduction

This thesis is centered around the design of remote collaboration systems for practitioners of physically skilled hobby activities.[1] Specifically, the goal of my research is to understand how to design, build, and evaluate systems that enhance the social and instructional experience of remote skill sharing in expert-novice groups for hobby activities. The body of my dissertation is formed by three interconnected studies with gardening as the hobby setting in which I have chosen to study remote collaboration. Gardening is a useful case to explore design for collaboration in hobbies as it has widespread intergenerational appeal and is viewed as a meaningful activity for individuals, families, and communities [14].

Through an initial participant observation study (Study 1) with nine experienced gardeners, I identified opportunities and design considerations for socio-technical systems in the activity space of the garden. The findings of this study highlight the influence of practitioners' social preferences as design considerations when facilitating skill sharing interactions. Given the existing need for access to expertise in instructional programs, the findings also provided motivation for further

[1] In physically skilled activities, expertise is embedded in physical movements and a history of interaction with materials [12]. Skilled hobbies can be defined as activities that privilege the joys of production over the value of the product [13]. Examples of skilled physical hobbies include gardening, woodworking, and soldering.

examination of remote guidance approaches.

I conducted this further examination of remote guidance by engaging 29 practitioners in an iterative design and evaluation of three extended reality (XR) applications in Study 2. XR is a technology that is increasingly being studied and used in remote expert guidance systems for skilled embodied activities in professional (e.g., industrial design and surgical training) scenarios. Study 2 provides an understanding of the perception among practitioners of the applicability of XR as an emerging technology for collaboration, specifically skill sharing, in informal hobbyist scenarios. The study findings also indicate directions for XR to support affective "connecting" interactions that help to build common ground [15] for learning between practitioners in these scenarios. Reconstructing and experiencing physical spaces for practitioners as 3D models with AR/VR devices is one such direction. It can be a powerful tool to provide environmental context for remote learning and augment connecting interactions with emotional context (e.g., value seen by different generations).

While there is much research that emphasizes sharpening sensory details of the models, these only partially correlate with user needs and possibilities for informal learning with AR/VR. Study 3 identifies the social context that users expect to capture when reconstructing personally meaningful physical spaces and objects to learn and connect with family and friends. Study 3 also acts as a capstone for my dissertation. It involves 1) the design of a multi-user remote XR system that combines learnings from Study 1 and Study 2 and 2) a scenario-based evaluation of the system in physical gardens by 18 gardeners in 8 intergenerational groups. The findings from this study shed light on perspectives around creating and sharing 3D models of meaningful objects and how they fit into the space of 3D contextual capture for instruction and connection. As part of this, I also highlight 1) implications for authoring and sharing 3D content that can represent shared memories, and 2) settings outside of gardens where exploring meaningful reconstruction of spaces and objects could augment intergenerational learning and social interactions.

1.1 Background

1.1.1 Skilled Activities and HCI: Why Gardening?

The context of computer-supported collaborative work has expanded beyond the workplace and into everyday lives and culture in the third wave of HCI [16]. Researchers are studying activities that occur in a diverse range of contexts, for example, in the outdoors, in nature spaces, recreational spaces, and in learning spaces for hobbies, crafts, and traditions. For activities that are embodied in nature where using and sensing through one's own body is important to learning and performing the tasks, research has often focused on the ways that experts hone their craft [17, 18].

In addition to developing individual expertise, however, practitioners are motivated to share their skills with friends, family, and others for broader goals that impact their communities (e.g., encouraging self-reliance through DIY [19,20]). Certain activity sites (e.g., community gardens) foster interactions between people from diverse backgrounds and serves as a site for the experiential learning of social and civic skills. For my dissertation, I chose to focus on the activity of gardening to understand the role that technology might play in achieving the practitioners' desired social, personal, and community objectives related to skill sharing.

Gardening is an activity practiced by people across ages and demographics whose impact can be felt at the personal as well as at the community level. However, skills related to food growing have seen a significant decline due to the industrialization and mechanization of food production [21]. Researchers argue the importance of reskilling in gardening and other craft practices as a way to return to authentic, deep, and hands-on engagement with broader issues affecting the community [22,23]. Specifically, for food production, these broader issues include environmental sustainability, food security, and social justice-oriented issues of increasing interest in Human-Computer Interaction (HCI) and Computer-Supported Cooperative Work (CSCW) [21]. Thus, researchers have specifically called for further study on how technology might support education around food production [4]. My work studies remote expert guidance approaches that attend to these broader motivations.

1.1.2 Learning How To Garden Remotely: Opportunities and Challenges for HCI and CSCW

Though there is certainly value in studying in-person skill sharing in gardening, this dissertation focuses on the topic of remote skill sharing for several reasons. First, past research has pointed out that the lack of local access to gardening knowledge, volunteers, and community support challenges the implementation of instructional gardening programs [24]. There is thus a need to understand whether remote skill sharing can yield benefits for those who lack access to local experts. Second, there are many open research questions around whether skill sharing in embodied, sensory-dependent activities can translate online. In-person learning of these activities is effective for a range of reasons, including the ability to provide tailored feedback to a novice in complex and subjective parts of a task [25] and to introduce the novice to the craft culture and vocabulary by contextualizing it through actions (e.g., pointing to features of an artifact or picking up the right tool) [12]. Specific to sharing gardening skills, past research indicates that novices gain skills and an understanding of the community culture through immersion in the garden environment with experienced practitioners [3, 26]. However, existing remote approaches largely take an asynchronous, non-immersive approach to share skills on a large scale [5, 6]. For example, people can use online forums to share pictures of their plants and ask questions (e.g., on Reddit)[2], or watch step-by-step guides where experienced gardeners share techniques (e.g., on YouTube). These approaches lack some of the dimensions that are central to gardening interactions: an immersive sensory experience [4,6] and social intimacy when interacting on-site with other practitioners [4,5,27]. My work examines whether XR systems might support these social and sensory dimensions and if they might be accepted by practitioners for this purpose.

[2]https://www.reddit.com/r/vegetablegardening/

1.1.3 The Potential and Challenges of XR in Skilled Hobbies

Collaboration using XR systems is an active area of research and development. There is much interest in the HCI community in understanding design considerations for remote guidance in embodied skilled activities. More recently, as compact, lightweight XR devices become increasingly available, research is being reinvigorated in several areas. One such application involves remote guidance, where a remote expert can assist, train, or share skills or ideas with a local user to solve a real-world task. For example, researchers have looked into real-time expert assistance [10] and professional training of novices [9] in skilled physical activities such as field servicing and surgical training. The capability of professional and consumer XR devices to reconstruct objects and spaces as 3D models for remote collaboration is also becoming increasingly powerful and ubiquitous. Even as our understanding of XR for remote collaboration in professional settings advances, an area that has been unexamined is how XR can support such expert-novice collaboration in skilled hobby activities. In skilled hobby activities, such as gardening, woodworking, or knitting, professional goals such as task accuracy or efficiency may not be the parameters around which to build the system. Through my work, I uncover other dimensions, such as social connectedness and affect (i.e. the emotional experience), that are central dimensions to inform system design for skilled hobby activities.

1.2 Research Approach

In my dissertation, I examined how remote collaboration through XR can be designed to support the sharing of skills in physical hobby activities such as gardening. I sought to understand the perceived role of technologies such as XR and design approaches that capture useful dimensions for hobby practitioners to share their skills in ways that are acceptable to expert-novice gardener groups in informal and intergenerational scenarios.

My dissertation research involved three studies in sequence. In my first study, I explored individual and social experiences in the garden activity space and identified design considerations for skill sharing with socio-technical systems. The findings from Study 1 have been published at ACM SIGCHI Conference on Human Factors in Computing Systems (CHI 2020) [8]. Using these design considerations from Study 1, I iteratively went from low to high-fidelity designs for remote XR prototypes to support skill sharing with feedback from groups of gardeners in Study 2. The evaluation of these prototypes by expert-novice dyads allowed me to understand perceptions of remote learning using XR and the potential for XR to augment social "connecting" interactions in informal learning settings. The findings from Study 2 have been published at ACM SIGCHI Conference on Computer-Supported Cooperative Work and Social Computing (CSCW 2022) [9]. In Study 3, I applied learnings from Studies 1 and 2 to build a remote collaboration XR system for an intergenerational setting that could be evaluated in a naturalistic setting. I investigated learning and connecting experiences specifically with reconstructions of objects and spaces in gardens that were meaningful to closely-related intergenerational groups of gardeners. The findings from Study 3 have been published at ACM SIGCHI Conference on Human Factors in Computing Systems (CHI 2023) [10].

1.2.1 Study-1 (Published at ACM CHI 2020)

This study laid the groundwork to understand sociality in the garden and how it influences skill sharing interactions between practitioners. I conducted participant observation sessions with nine experienced gardeners at their gardening sites and qualitatively analyze the data from the sessions to address the following research questions:

- How do practitioners engage socially as they practice their hobby?
- What kinds of social interactions facilitate skill sharing in the garden?
- What are some key opportunities for computer-supported collaborative work in this space?

The findings of the study highlighted design considerations for teaching and learning in the garden space based on how practitioners engaged in collocated or remote social interactions with others in their community. I found that learning occurs through collocated interactions inside the garden, using a range of digital resources outside the garden, and even indirectly by observing other practitioners' gardens. Based on my findings, I identified opportunities for remote approaches to skill sharing, including video telepresence and XR. In Study 2, I examined how one of these types of technologies, XR, can facilitate the immersive and embodied interactions that practitioners associated with gardening. A topic I return to in Study 3, based on findings from Study 1, is ensuring that digital approaches are inclusive of the intergenerational and mixed-ability groups who benefit from gardening.

1.2.2 Study-2 (Published at ACM CSCW 2022)

In this study, I determined the feasibility and reveal considerations for remote approaches for learning in expert-novice groups in the garden. From Study 1, XR appeared to be a promising approach to support embodied interactions and immersion in the remote activity environment. I pursued this direction by conducting user-centered design sessions with 29 gardeners in three phases: obtaining feedback from participants on low-fidelity prototypes, developing XR design probes based on feedback on the prototypes, and finally evaluating the XR probes. The research questions addressed in this study include:

- What are practitioners' perceptions of using XR for skill sharing?
- What are the important dimensions of the design space and design scenarios for skill sharing using social XR systems?

Through this study, I identified ways that XR systems for skill sharing could augment interactions that connected practitioners with each other's motivations and the activity space. This included visualizing community (e.g., environmental) impact and communicating how experts measured by using their senses. In my findings, I also found a pervasive theme of connecting through affective connecting interactions. These interactions included sharing stories about objects in the garden, often with the broad goal of passing on a love for the activity. The objective of designing to connect differentiates this work from existing research on remote expert guidance that uses XR for professional settings (e.g., surgery) and from prioritizing result-oriented outcomes (e.g., accuracy and completion time). These findings motivated the research focus of Study 3 to further understand how connecting interactions in hobby learning settings can be augmented using XR.

1.2.3 Study-3 (Published at ACM CHI 2023 and Awarded Best Paper)

My third study derives from the previous two studies, where XR that was centered around connecting activities appeared to be a feasible approach to remote skill sharing in hobby settings. Additionally, I returned to two needs I identified in the previous studies. The first is a need from Study 1 to design for an intergenerational setting by involving and designing for the values and constraints of older gardening experts. Second, a finding from Study 2 was how interaction with virtual objects and remote environments in XR affected connection (e.g., sharing flowers and stories) as well as instruction (e.g., measuring by observation). The ability to work with and share virtual replicas of physical objects (e.g., virtual tools, plants, or garden plots) was found to be a key advantage of the XR approach over conventional video chat, especially for connecting interactions. However, there is a lack of understanding of the social affordances of the objects in the hobby practitioners' activity space and how that would translate to virtual replicas in XR environments. In Study 3, I built and deployed a high-fidelity XR system in the naturalistic setting of participants' own gardens. I evaluated the system through observation of participants' system usage, and semi-structured interviews to evaluate social presence and connection with mixed-ability inter-generational groups.

The objective of this study was to expand our understanding of how to support connecting and instructional interactions between inter-generational, mixed-ability groups using virtual representations of objects that were meaningful to users in the remote activity environments in XR. The research questions addressed through this study include the following

- What is the important social and sensory context that can influence informal XR users' remote experiences with virtual representations of real activity spaces and objects?
  - What context is important to users for learning experiences with reconstructed spaces and objects?
  - What context is important for connecting interactions with reconstructed meaningful spaces and objects?
  - What context is important to users when sharing reconstructed meaningful spaces and objects?
- What are design considerations for XR to support the values and goals of an informal inter-generational group interacting with the virtual representations?

1.3 Organization

This thesis is organized as a three-paper thesis. Chapters 2-4 cover a description of the methods, findings, and discussion points from Studies 1, 2, and 3 respectively. Chapter 2 consists of my article published at ACM CHI 2020 [8] from my participant observation study (Study 1). Chapter 3 consists of my article published at ACM CSCW 2022 [9] for the iterative low to high-fidelity prototype design study (Study 2). Chapter 4 consists of my article published at ACM CHI 2023, for the scenario-based evaluation of working with reconstructions using my final remote XR system (Study 3). Each chapter will include subsections that describe in detail the motivations, background literature, methods employed, findings, design implications, and limitations of the studies. Chapter 5 concludes this dissertation with a summary of Studies 1-3 along with my contributions to the field of HCI and XR design and reflections on my learnings through this thesis.

Chapter 2: Sociality and Skill Sharing in the Garden

2.1 Overview

Understanding the existing experiences of practitioners of skilled hobby activities, their relationship with their activity space and other practitioners, and dynamics with technology is crucial for designing effective technology that enhances their activities. In the first study of my dissertation, I investigated the role that collaborative and social computing technologies might play for practitioners of gardening as one such hobby activity. Gardening is an activity that involves several dimensions of increasing interest to HCI and CSCW researchers, including recreation, sustainability, and engagement with nature. I conducted participant observations with nine experienced gardeners aged between 22 and 71. Through this process, I discovered that gardeners constantly adapt their surroundings to accommodate their preferences for social interaction. They share their physical skills and assist others in tuning into sensory information in person, but also use the features in their garden to facilitate learning for others who observe them and their spaces. From these findings, I discuss the concept of sociality within gardening and identify design considerations for skill sharing using collaborative technologies in this context. These design considerations also guided my subsequent research focus on expert-novice and informal learning interactions in studies 2 and 3.

This chapter on Study 1 is adapted from my paper on "Sociality and Skill Sharing in the Garden" [28] published in the proceedings of the 2020 ACM SIGCHI Conference on Human Factors in Computing Systems. As the first author, I led the study design, data collection, analysis, and written and oral presentation of this work.[1]

2.2 Introduction

HCI researchers are examining outdoor activities and nature spaces as sites of recreation, learning, and social interaction. Gardening is one such outdoor activity with ties to other topics of interest in HCI such as food sustainability and civic engagement with environmental issues. Gardening is an activity that builds community and increases residents' attachment to their neighborhood [29]. It fosters interactions between people from diverse backgrounds and serves as a site for the experiential learning of social and civic skills such as leadership, community organizing, and cultural competency [29, 30].

People are also drawn to gardening for opportunities to spend time outdoors and with family [14]. A 2014 report estimates that one in three households in the United States engage in food gardening, or urban agriculture [14]. These 42 million households include people of all ages. Yet, not all groups have equal access to getting engaged in gardening. Access to land for gardening in an urban setting

[1] My co-author, Dr. Amanda Lazar, provided feedback and suggestions throughout the project and paper write-up.

is limited [31], a lack of gardening knowledge can limit participation [24], and for some groups with mobility constraints, technology typically focuses on indoor living rather than outdoor spaces [32, 33]. With a growing interest in the opportunities it presents for technological applications for group interaction, and in the work still needed to promote access to this activity, gardening appears to be an area ripe for HCI research.

However, when considering design in the garden space, it is required to turn to the body of past research that has found that practitioners are sensitive to how technologies are introduced in the garden space. For example, automation using sensor networks can be perceived as obstructing the sensory, embodied, emotional feeling of engaging directly with nature [4, 6, 27]. Gardeners may trust their own localized, developed knowledge over scientific models [34]. Poorly designed technology can also impede important social practices in the garden, for example, the transmission of skills from experienced to novice gardeners [6]. The drawbacks of purely technological approaches when engaging gardeners, paired with the social nature of gardening, point towards exploring social-computing design approaches as a fruitful area of research [5, 35]. Understanding the potential role of social technologies in this space requires an examination of where sociality exists in the garden, as well as the particular kinds of interactions that might need to be supported.

Our research takes, as a starting point, findings from past work: that gardening is sensory and emotional, with social practices that have been built around these activities over time. Given that past work has typically sought gardeners' perspectives on technologies that transmit information to gardeners (e.g., soil quality [36, 37] and temperature [35] sensors), we return to the garden setting with an ethnographically informed approach, engaging in participant observations with nine gardeners to identify opportunities for HCI. Our paper offers three contributions. First, we provide an understanding of sociality in terms of where it exists in the garden and how gardeners configure desired levels of social interaction, for example, through physical arrangements such as letting vines grow over a fence to obscure the view of those passing by. Second, we highlight skill sharing as a key domain for social design in this space. We find that this process of skill sharing is supported through different levels of engagement with practitioners: in addition to direct interaction and the use of digital platforms, practitioners learn techniques and other information through the observation of others' gardens. Finally, we contribute design considerations for collaborative technologies in outdoor settings with implications for embodied skill sharing and inclusion. We suggest that technology designed for social computing in the garden should balance respecting dynamic sociality preferences with motivating community engagement and collaboration.

2.3 Related Work

Below, we discuss research on technology for outdoor activities in nature spaces, the garden as a site for community engagement, and perspectives on technology in the garden.

2.3.1 HCI in the Outdoors

Recent HCI research situates technology design in a range of outdoor activities. These include recreational activities (e.g., tourism [38], scuba-diving [39], and paragliding [40]), fitness (e.g., running [41], wall-climbing [42], and cycling [43]), and nature activities (e.g., hiking [44], foraging [45], and monitoring wildlife [46]). Design in this space has considered motivations to engage outdoors as well as the value that technology brings to personal and shared experiences. Some research on outdoor activities draws on social facilitation theory [47] to support social interaction in fitness groups through revealing information such as the speed of runners [41] and heart-rate of cyclists [43] to others. These studies discuss insights from in-situ presentations of individual and group performance metrics and their potential for supporting group togetherness and motivations for fitness.

In contrast to work that supports social experiences around outdoor activities, other research helps people disconnect from other people and become more immersed in nature. For example, research has supported purposeful solitude in nature by informing individuals of nearby hikers [44]. With the rising interest in HCI in the outdoors, it is important to understand what design considerations exist for supporting sociality in outdoor spaces. In our work, we find the importance of acknowledging varying, rather than static social preferences in outdoor spaces — a concept that has previously only been considered in a traditional indoor office setting. We discuss how designing for learning or skill sharing in the garden space should account for these varying social preferences.

Nature spaces are another domain of interest in outdoor HCI, including research that explores the role of technology to support collaboration. Research has examined the design of collaborative technology for search and rescue teams trying to maintain situational awareness in wilderness [48] and to support simulations in high-risk outdoor recreation areas [49]. Nature spaces also provide an avenue for environmental learning. For example, Soro et al. describe an IoT "Ambient Birdhouse" designed to interest children in engaging with nature by becoming more aware of bird calls and discuss how it could be used as a catalyst for learning and socializing [50]. Liu et al. designed three wearables for mushroom foraging to "offer a vision of wearables extending our human sensory capacities into the environment" [45]. This vision offers people the capacity to "notice, attend to, and become struck by nonhuman lives" and, in the case of one of the prototypes, also share the information that they gather with others [45].

2.3.2 Community Engagement in the Garden

A common approach in sustainability HCI research is to design for community engagement to encourage strong civic activity around pro-environmental goals. For example, YardMap supports professionals and citizen-scientists in mapping personal carbon-neutral yard practices, learning about their local environment, and discussing their potential impact on habitats [51]. The inclusion of people from different cultural backgrounds [52] and expertise levels [51] through knowledge-sharing [5] and capacity-building [4] is seen as an important mechanism for building sustainable communities.

Jrene Rahm's work, centered around an inner-city youth gardening program, highlights the role of active social participation in creating opportunities for developing expertise as a novice [26]. Novices, through situated learning, gain skills and an understanding of the community culture through their interactions with peers or more experienced practitioners and immersion in the garden environment [3, 26]. The ways that gardeners become experts in using their senses to notice and observe lead to opportunities to support people in new ways of engaging with the world and with other practitioners towards more sustainable futures [6, 27, 53]. However, researchers have also noted the tensions that arise when designing for engagement in communities with diverse expertise levels. For example, managing the territorial behaviors of experts is important in encouraging participation from novices and allowing them to develop a feeling of attachment and ownership towards the community [54]. In our paper, we acknowledge the value of garden spaces in cultivating a sense of community and engaging with other practitioners for skill sharing. We discuss this in light of the tensions that we find in encouraging community inclusion while maintaining ownership of the garden space.

2.3.3 Gardeners' Perspectives on Technology

Several studies have focused on gardeners in community and residential settings. This past research has found that gardeners do use many digital tools, often to share information or support coordination. For example, Wang et al. analyze collaboration between gardeners, finding that they use different tools for information and knowledge sharing as well as scheduling work activities [55]. In a study of handwork, Goodman and Rosner note that though gardeners and knitters use many different digital tools, they define their values in opposition to stated negative characteristics of technology [27]. For example, being *engaged* rather than *disconnected* means "committing to the material details of making objects oneself," rather than using a system to cut oneself free of the task of watering [27].

A common theme of the body of work on gardening is the tensions that arise with technology. For example, Lyle et al. highlight how gardeners learn through experimentation and observation, as well as the importance of sharing knowledge between community members [5]. In this context, Baumer and Silberman present sensor nets for data-driven gardening as a case study of when the implication is *not* to design a particular technological solution [35]. Sensing systems to support automation of tasks or decisions (e.g., automatic watering based on soil moisture) appear to be viewed negatively by gardeners in much past research, as they are seen as interrupting existing values and processes, such as direct interaction between gardeners and plants [4,6] that help gardeners develop environmental knowledge and intuition [6]. Further, automation can interrupt the transfer of knowledge between senior and novice members of the community [6].

This past literature lays the groundwork for investigating collaborative technologies and social computing in community and residential gardening as a fruitful area of investigation, in that it matches the social and collaborative nature of gardening and moves away from purely technological solutions [35]. Understanding the potential role of collaborative technologies requires filling a gap in our understanding of how sociality manifests in the garden. In our paper, we discuss our findings on two such components of sociality: how a practitioner's sociality preferences are reflected in their working space, as well as the level of active engagement with other practitioners when teaching and learning skilled activities in the garden.

2.4 Methods

Fieldwork was conducted over the summer (June through September 2018) in the Mid-Atlantic region of the United States. Below, we describe the study procedures, participant information, and our analysis.

2.4.1 Study Procedures

We took an ethnographically informed approach to data collection and analysis [56]. Sessions involved a 15-minute interview, a brief drawing prompt, and a 60-minute participant observation session. The interview included questions such as participants' motivation, frequency of gardening, and self-described level of expertise. In the drawing prompt, participants drew the physical sites where they gardened, including the places that held meaning as well as where they grew different plants and kept tools. In the participant observation, gardeners were asked to engage in activities that they normally would do around their garden. The first author shadowed and worked alongside gardeners and asked questions when relevant to the task at hand. This included, for example, questioning how gardeners made

ID	*Age*	*Gender*	*Ethnicity*	*Observation Site*
P1	60	Male	-	Public Community Garden
P2	26	Female	White	Home Garden
P3	61	Female	White	Home Garden
P4	37	Male	Indian	University Community Garden
P5	-	-	-	Private Community Garden
P6	-	-	-	University Community Garden
P7	37	Female	White	University Community Garden
P8	71	Male	African	Public Community Garden
P9	22	Female	White	Shade Garden (Ornamental)

Table 2.1: Self-Reported Participant Information ('-' indicates participant wished to keep information private).

particular decisions.

Data collected included the sheet from the drawing prompt, observation notes, video, and audio recordings. The video was collected with a head-mounted GoPro Hero 5 action camera. Our sessions yielded approximately 800 minutes of audio and video recordings (93 minutes per session on average). In parallel with data collection, both authors spent time becoming familiar with the process of gardening. The first author participated in weekly volunteer sessions at the university community garden for four months, and the second author engaged in gardening in her backyard. These experiences informed the study protocol and our understanding of gardening practices and the process of learning gardening skills.

2.4.2 Participants

Nine participants who self-identified as gardening regularly were recruited through local community garden e-mail lists, fliers posted on campus, word of mouth, and snowball sampling. Participants were between the ages of 22 and 71 (average=45 years, std. dev=19.3 years). All sessions involved participant observations, but four individuals did not engage in the initial 15-minute interview (P5, P6, P7, and P9) and two did not engage in the drawing session (P1, P6) due to time constraints.

We attempted to recruit from a range of gardening configurations to understand how experiences may vary in different spaces. Participants gardened in different arrangements, from private backyards to public community gardens[2] (Table 2.1). All participants grew food items, the most common being tomatoes, peppers, and herbs. Almost half of the participants grew flowers for themselves, and the majority grew flowers for pollinators. During the participant observation, we asked individuals to engage in whatever tasks they might naturally be doing that day. This ended up including a variety of activities: weeding, watering, trellising, harvesting, decorating, and just relaxing in the garden.

2.4.3 Analysis

Our constructivist grounded theory approach to analysis [57] was as follows: the first author open-coded two transcribed interviews and three sets of observation notes to create a preliminary set of codes and emerging themes. The research team met to discuss these codes over several sessions and became interested in themes relating to *Sociality* (with codes such as "being accessible to passersby," "having informal boundaries in the shared plot," and "viewing the garden from an outsider's point-of-view") and *Skill Sharing* (with codes such as "learning from someone who seems more experienced," "observing decorations on neighbors plot,"

[2] A community garden is a single piece of land gardened collectively by a group of people. Table 2.1 indicates whether these gardens were situated on private or public land. Public community gardens are usually managed by the local government.

and “sharing a photograph to describe plant condition”). The first author then coded the rest of the transcribed interviews for these themes, adding additional codes as they emerged. The research team related codes to each other through an iterative process of memoing and theorizing, engaging in constant comparison of data to understand and refine a set of high-level themes.

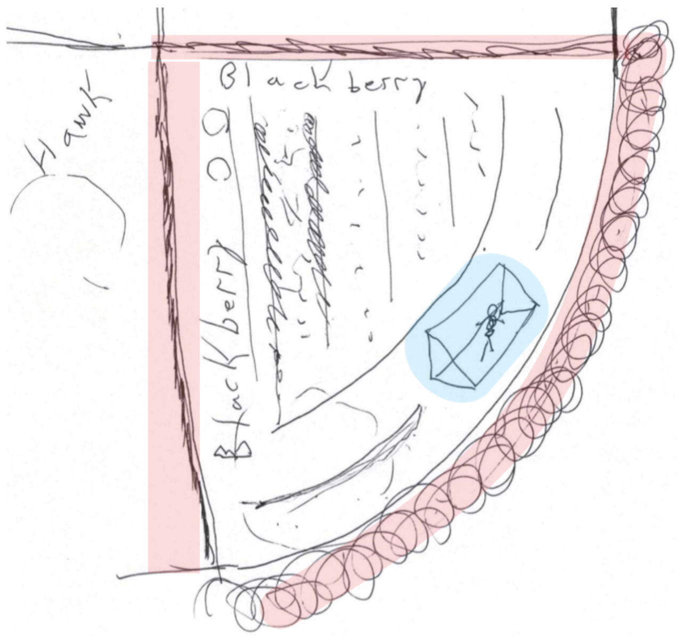

Figure 2.1: P5’s drawing of his “secret garden” shows the fence (highlighted in red) and a meditation hut (highlighted in blue).

Figure 2.2: P5 walking next to his fence covered with blackberry and honeysuckle (left) and standing in his meditation hut (right). These created a sense of privacy.

2.4.4 Limitations

Though participants were diverse in the range of settings in which they gardened, the small number of participants, all from the US, and our approach to recruitment and analysis means these findings cannot be generalizable. The emphasis on skill sharing that arose was likely shaped by our method of participant observation and participant roles in gardens (e.g., working in a community learning garden). Future work is needed to examine a more diverse and comprehensive sample.

2.5 Findings

In this section, we discuss where sociality arises in the garden and the ways gardening skills are taught and learned. We find that gardeners configure desired levels of sociality. One way they do so is through physical arrangements. Elements such as the type of fencing (e.g., honeysuckle-covered fences or a chain link fence) can indicate ownership and manage interaction with other gardeners and passersby. One kind of interaction that takes place in the garden is the learning and teaching of skills between gardeners. Skills are shared directly, and also indirectly through observation of others' gardens.

2.5.1 Configuring Sociality

Participants engaged in different levels of sociality. This appeared in the actual ways they went about gardening: P5 intentionally gardened alone, P2 worked with her partner on most major tasks, and P4 liked to engage with and learn from others in his community garden. P3 touched on the ways that different gardeners might be drawn to different kinds of gardening arrangements. Where she gardened, it was *"close, you share a lot of space... people that want to be on their own, they wouldn't come here."* Many gardeners, though, were not solely social or private gardeners – they chose to be private or social depending on their mood or the activity they were doing.

2.5.1.1 Managing Interactions With Other Gardeners

Gardeners use physical features of gardens, such as raised beds and hedges, to support desired types of social interactions. P1 explained that where he gardened, plots involved *"raised beds with wood around them so we each know our boundaries."* P5 configured his space by letting vines grow on top of existing separations of plots in his community garden to get more privacy: he pointed to the fence on his plot (Figure 2.2) *"where all the honeysuckle grows... [the] privacy gives me the secret garden feeling that I like."* He appreciated being alone in the garden to find space for introspection, meditation, and the feeling of getting away from culture. P5's case shows a gardener using natural and built features to create a more private space in a community garden. In a contrasting example, P3 sometimes shared tasks with her neighbors in a backyard that included both their garden spaces. It made a private space more social by bringing together *"people that are okay being close to other people."*

In P5's example, letting honeysuckle grow wild created a desirable social arrangement for him. P9, on the other hand, spoke about how she arrives at a socially desirable space by picking up debris – though she leaves leaf litter and smaller sticks as a way of *"keeping it natural"*. P9 clears the pathways in the garden of debris to make it *"functional for everyone,"* including those with disabilities. She explained that part of the community learning garden where she worked was designed to comply with the Americans with Disabilities Act[3], *"So people in wheelchairs or with disabilities can easily access this part of the garden, and with the raised beds they can participate in gardening just as well [as] people who don't have a disability"* (Figure 2.3). P9 appreciated *"how well this space includes a wide range of people."*

Like in the example above, physical configurations (in this case, the removal of large debris) are ways that gardeners reach desired levels of sociality not only based on personal preference but also based on policy or community-wide decisions. Some community gardeners talked about how garden managers played a role in enforcing community rules of particular sites. According to P6, managers resolved issues with a plot that could affect other members, such as directing members to remove weeds that could spread to other plots. Managers also disseminated news related to group activities, such as putting down wood chips on paths. Even when gardeners were coordinated to support adherence to policies about community space, privacy preferences could be preserved. P1 explained that *"the manager can send a message to all of us ... we see there's a list of emails, but we don't know which necessarily*

[3]The ADA is a civil rights law that prohibits discrimination against individuals with disabilities in all areas of public life, including jobs, schools, transportation, and all public and private places that are open to the general public. For more information, see https://www.dol.gov/general/topic/disability/ada.

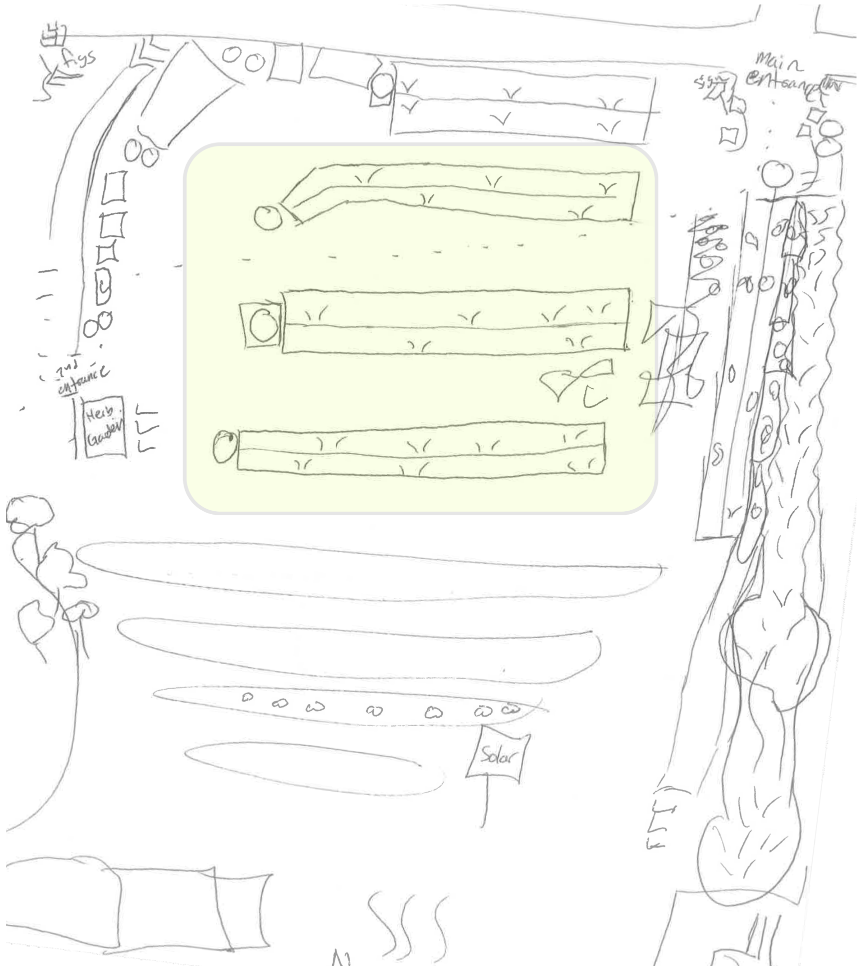

Figure 2.3: Drawing by P9. ADA-accessible teaching spaces are highlighted in green and open to all visitors.

from the address refers to which person. [We] certainly don't know which person refers to which plot."

2.5.1.2 Interaction With Those Outside the Garden

Participants also configured social interactions not only for fellow gardeners but also for the broader community that comes into contact with gardens both directly and indirectly. In Heitlinger et al.'s study, a central value of a farm garden is inclusion [4]. In our study, we found that a commitment to inclusion shared by many gardeners was in tension with preferences to create divisions between the garden and the outside world. Participants saw boundaries that they created or that were features of the space not only as important to keep out animals and people who might take produce or flowers, but also to create a sense of privacy. P3 enjoyed seeing passersby who would complement her flowers, saying that, *"[it] is very nice because you see people coming, passing by ... They are far away enough that they are not in your space..."*. Her garden was separated by an informal boundary created by elevation from the passersby in a shared green space.

Though these separations were important for gardeners to achieve a level of social interaction that was desirable for them, they did think about the ways that some barriers to the outside world might come off as uninviting and worked to create a more welcoming space without necessarily letting others into the garden itself. P1's plot in the community garden had a wire fence with a lock on it. When asked if the garden saw visitors, perhaps children and their parents, from the bordering playground he mentioned that the fence might have unfortunately created a feeling of exclusion for the community: *"There's a sense, perhaps because of the fence, that the gardeners want to be left alone and outsiders don't bother [with them]."* P1 discussed how he decorates his garden, for example, with flags for the US holiday of July 4th (see Figure 2.4), to show *"community sentiment."* This was so *"people outside the fence and [who] can't get in might feel a little less excluded and maybe it's good public relations for the garden."* P1's chain-link fence allowed individuals to see the decorations he placed in his garden. P8 described an arrangement outside a community garden that encourages community inclusion while preserving boundaries. Benches were arranged just outside the fence, in a way that invited outsiders to sit and observe the garden.

Figure 2.4: P1 decorated the garden for a national holiday with flags, visible through the chain link fence, to show community sentiment.

While some participants, like P7, described gardening as an opportunity to *"disconnect from a lot of technology,"* smartphones and social media played a visible role when managing interactions with people outside the garden as well as those in its physical proximity. Participants (P1, P3, P4, P6, P7, P8, and P9) frequently mentioned capturing photographs using their smartphones and sharing them, for example, on Facebook and Instagram. These were usually used to enable a passive form of interaction through the posted photographs and other content like, for example, comments that compliment the garden (P1, P4, and P8).

Gardeners also described encouraging active involvement with the garden through volunteering opportunities (P6, P7, and P9). P4 describes one such activity where he posted online to invite others to make and share a sauce with peppers. In general, we also find that participants described interactions of a mostly positive nature (P1, P3, P4, and P8), both online and offline. P1 explains that it's *"a polite thing"* since *"people get sensitive in the garden. Something about the place, something about the activity, you very much want to hear praise."* Though social sharing was an important usage of photographs, photographs were also sometimes taken to keep a personal record of the garden's progress over time (P1, P3, and P8). For example, P3 described taking, *"photos of the flowers, because it's fun to remember when they bloom or just they are beautiful."*

2.5.1.3 Cultivating Desired Emotional States and Relationships

In addition to providing or preventing others from access to gardening spaces, gardeners also used physical arrangements to cultivate certain emotional states for themselves. P2 and P3 placed chairs in or within view of their gardens and spent meals and time with their partners enjoying the ambiance. Two gardeners described feeling meditative when gardening, with P5 reserving a space for meditating in the garden – his *"little meditation hut"* (see Figure 2.1). These findings are consistent with work from anthropology discussing boundaries within the garden itself, where, "there are also separations between different areas and particular functions and activities associated with each" [58].

Plants and objects in the garden also became ways that participants connected with others outside the garden. Over the course of the study, the first author was offered the following items from participants: beans, tomatoes, eggplants, peppers, strawberries, ground cherries, basil, and three types of flowers – zinnia, globe amaranth, and ageratum. A few gardeners grew items specifically to give as gifts, such as P2 who grew catnip for her friend's cat. Past work has also found that gardeners share produce with friends or fellow gardeners [4, 27]: we find that gardeners also gave away produce to benefit the community at large. P7 explains, *"We do harvest a lot of stuff and donate it to the campus pantry ... because 15 percent of our student population is food insecure."* P4 and P8 shared produce with community members at their place of worship. P4 describes they do this in part because *"it helps save the [place of worship] some money."*

In addition to connecting to other individuals or a broader community in the present, participants used gardening to reinforce feelings of connection to people or places from the past. P8, who grew hot peppers on one of his plots, referred to how people from his native country love those peppers. P3 described how her hellebore plant *"reminds me of my mom, because she always had them,"* and her gardening toolbox housed a tool that reminded her partner of his father. She called these *"memory objects."* These examples highlight how the garden is shaped to create a personal space that reflects the gardener's relationship with a community or loved one.

2.5.2 Skill Sharing in the Garden

A form of interaction that we discuss in this paper is skill sharing in the garden, a recurring theme in our interviews and observations. More experienced gardeners in our study often had formal and informal teaching roles, but even a master gardener such as P7 acknowledged that *"you never stop learning in this job, which is one of the other reasons why it's so enjoyable."* We detail the different forms in which knowledge and skill sharing about the sensory-rich, embodied practices of gardening took place.

2.5.2.1 Tacit Knowledge Communicated in Co-Located Learning

In past work, being physically collocated with other gardeners allowed novices to get help from more experienced individuals, for example when dealing with slugs [55]. Our findings reveal that co-located gardening enables gardeners to benefit from verbal instruction, but also from non-verbal information and the communication of tacit knowledge.

Most participants described learning gardening skills from others with more experience in face-to-face interactions. P4 told us that when he was starting out learning to garden, he spent time talking to experienced gardeners and *"picking their brains."* Even now, he enjoyed being in a community gardening setting, because with all the activity in the space, *"I can learn a lot. I feel like it's made me a better gardener."* In our participant observations, we saw the importance of face-to-face sharing to teach embodied and sensory skills. The first author was taught, for example, to measure ripeness using touch by P8 and P2, to find locations for incisions on the plant, and the safe handling of pruning shears by P7. Another anecdote that indicates the importance of face-to-face interaction to communicate knowledge took place when P9 mentioned that it was sometimes, *"hard for me to explain a plant versus a weed... especially if [the people I am teaching] are newer to gardening."* The weeds P9 and the first author were looking for in that spot in the garden were from the dicot plant group. When the first author said that he didn't know what a dicot plant was, P9 showed how the orientation of veins was a differentiating feature. While tracing the outline of the leaf veins with her hands, she explained: *"You have this vein here, but then you have these little veins coming off the sides ... so they're not parallel."* This information would have been difficult to communicate without a shared field of view, gestures, and haptic feedback from the veins: all elements that can be seen as inherent to face-to-face interaction.

Figure 2.5: P9 showing the first author the difference between leaf venation of a monocot (left) and dicot (right).

As the first author worked in this setting and was taught to notice plants in different ways by experienced gardeners, he began to develop a competence for recognizing different plants based on sensory information. P2 presented a contrast between the leaf texture of pumpkin plants, which the researcher found to be *"crackling"* (excerpt from field notes), and gourds leaves, which P2 explained were *"much softer than the pumpkin."*

2.5.2.2 Continuing To Learn Outside the Garden

The affordances of face-to-face skill sharing were clear in our findings. However, as has also been found in past work, gardeners also learned by using a range of digital resources to find information [27]. In our study, this occurred predominantly via text and images, such as how-to blogs (P1), social media messages (P4), and YouTube videos (P2, P5, and P8). P4 described sharing an image of a diseased plant with people at a nursery to identify the disease, and P1 told us that he posted pictures of potential weeds online so others could identify them. Individuals also used digital technologies to get information from those they knew: P3 showed us a picture she had messaged to her friend so that the friend could remind her of a name of a plant (Figure 2.6).

Participants appeared to take distinct roles in their online engagements, as either consumers or producers of information. Some participants (P1, P2, P5, and P8) acknowledged they were more likely to be consumers of information than creators. Strikingly, these gardeners had self-identified as experienced and taught us during participant observations. However, they felt less comfortable sharing their knowledge online than in-person. For example, P1 has been gardening for several

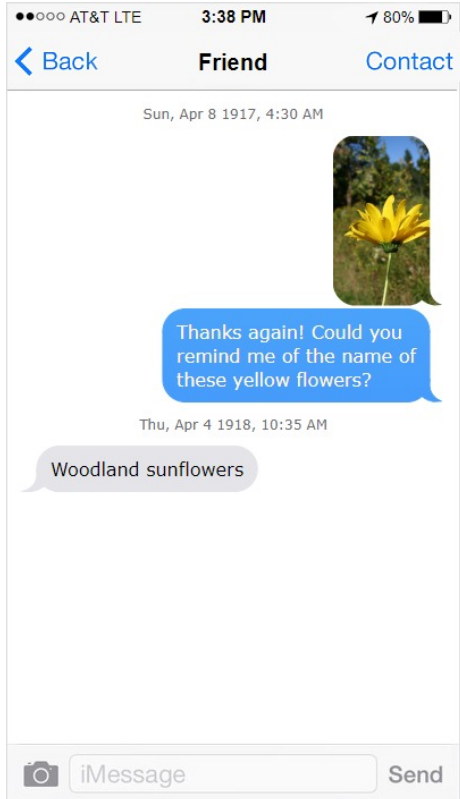

Figure 2.6: Mock-up of a mobile screenshot showing how P3 asked for her friend's help with identifying a plant.

years but when discussing helping identify plants on a website he frequents, he feels he *"can't do that. Online, people know a lot more about [that]."* On the other hand, P7, who had been a master gardener, felt *"people are going to learn from me instead of me learning from them."*

2.5.2.3 Learning From What Is Left Behind by Others

Gardeners also learn without the active involvement or even presence of others by examining the state of others' gardens and gardening configurations. Past work has found that gardeners learn from observing what farmers are doing, for example, by looking at the produce in farmers' markets to understand what is in season [5]. We found that gardeners can also learn techniques from observing farms. P8 described experimenting with a plastic sheet on the ground to prevent weed growth after observing this strategy in farms and searching online to understand the reasoning for it (See Figure 2.7).

Figure 2.7: P8 used plastic sheeting after observing its usage by farmers.

One participant observed others' gardens not just to learn from them, but to gauge how his garden might be faring. P5 said that when on vacation, *"I'll look at other people's plants to see, 'Okay, where are your tomatoes going now? What's the story here?' ... Because, if I'm in [state X] and we got a heat wave [in] both [state X] and [P5's home state Y], I'll kind of know what to expect when I get home."* By looking at similar plants in states with similar weather conditions, P5 can gauge the status of his plant remotely. In these examples, we see that it is not only the experienced practitioners such as farmers whose plots can reveal information and help relative novices make sense of why they do what they do. Novices can also compare their progress by observing the gardens of their peers.

Learning new skills via observation of other gardens happened within our research team during the course of the study. We observed that P1, P1's neighbor, and P3 all had deer antlers or bones lying around in their gardens to provide nourishment to the animals and the soil (Figure 2.8). During the writing of this paper, the second author found that the first author had added a small 3D-printed set of antlers to his indoor plant in the office (Figure 2.9). Reflecting on his experience, the first author saw this action as a novice imitating the experienced gardeners as a way to feel more connected to the community of gardeners with whom he had worked. This goal has been described in learning theory research as motivating and providing meaning to the process of becoming knowledgeably skillful in situated learning [3].

Figure 2.8: P1 pointing at deer skull (left). P3 holding deer antlers (right).

Figure 2.9: Researcher's 3D printed antler.

2.6 Discussion

Our findings reveal an understanding of sociality in the garden. We find that sociality exists in co-located and remote interactions with other gardeners, as well as with the broader community outside the garden. Practitioners' sociality preferences are non-static and diverse. The garden space is designed purposefully in response to these sociality preferences to allow or restrict access to outsiders or other practitioners. Based on these findings, we present the following considerations for HCI in designing for collaboration in the garden. Specifically, we consider how the way sociality exists in the garden bears on teaching or learning skills associated with the activity. We also consider social computing approaches in the garden space for creating a sense of community inclusion. Given that past work urges designers to be mindful of the interactions between technology and practitioner sensibilities [5, 6], we also present potential tensions that arise in introducing technology to the garden in each section.

2.6.1 Teaching and Learning Embodied Skills in the Garden

Promoting lifelong learning is described as one of the "Grand Challenges" for HCI [59]. Our work highlights skill sharing as a key domain for design in the garden. Teaching and learning are regular practices of the participants we studied. Skills are continuously gained and refined, both through direct interaction with others as well as through observations of others' gardens. Yet many individuals lack opportunities for in-person learning, and a lack of gardening knowledge and access to experts has been linked to the failure of programs intended to foster gardening skills [24]. Below, we describe opportunities to leverage the expertise of experienced gardeners as a way to support multigenerational interaction and cultural exchange through observation and practice.

Learning by doing, under the instruction of expert family members and friends, was an important way that many participants in our study – as well as the first author as a participant observer – gained initial gardening skills. Though participants spoke of using platforms such as Facebook to look up gardening questions or sending a picture to their friends on the phone, these forms of media are not sufficient for learning many of the embodied skills key to gardening. In other settings, research has examined ways to support embodied learning through skill demonstration, when an expert and novice are not co-located. Future work can draw on past work on embodied learning to encourage interaction with sensory stimuli that mimic an expert practitioner, for example, imitating a projected video of an expert [60] or experiencing vibrations synchronized to the movement of an artisan using a tool [61].

There are also open opportunities to create remote real-time skill sharing experiences for outdoor activities such as gardening that draw on the telepresence literature. This includes real-time interaction between distributed groups of practitioners using, for example, ego-centric feedback [62] and tangible interaction with remote physical objects [63]. However, when considering harnessing the expert experience of gardeners, it is important to note that while some experienced practitioners, such as participant P7, might feel confident that gardeners will learn from them, others, such as P1, might be less inclined to share their knowledge. Taking the initiative to share information, rather than primarily being an information consumer, may depend on whether the practitioner feels that other people in the group *"know a lot more,"* as P1 put it. This self-perception of the practitioners' expertise relative to the group is an important consideration when encouraging knowledge-sharing behaviors. Some may be far more willing to share one-to-one than in larger groups.

Our study adds to past work on how gardeners learn from direct interaction with other gardeners [26]. We find that learning can also take place through making sense of the traces left by other gardeners, with some gardeners mimicking techniques that they learned from their observations. The traces that participants focused on often had to do with gaining an awareness of how more experienced gardeners might approach sustainability. For example, P8's technique of plastic sheeting was based on how farmers discouraged weeds without chemicals. P3 and P1's ideas of placing antlers in the garden came from an understanding of the necessity to nourish the soil and other animals. HCI research on gardening is often motivated by sustainability [4, 5]. So one design opportunity in this direction is to preserve and share the traces of skilled gardeners' actions related to sustainable behaviors and techniques.

2.6.2 Designing for Varying Social Preferences

Participants created spaces that reflected their sociality preferences using different kinds of boundaries as a way to manage interactions with other gardeners and people outside the garden. Below, we describe the implications of these findings for how social technologies in the garden might be received.

In considering social technologies in the garden, it is essential to consider the ways that preferences for sociality are not constant. In our data, gardeners' preferences varied with changing moods, tasks at hand, and the constraints and possibilities of a particular gardening space. In accounting for varying sociality preferences in the design of collaborative systems, researchers have explored concepts like interruptibility and signaling availability primarily in the context of indoor work settings [64, 65]. As one example, researchers have studied whether interruptibility can be estimated from whether productivity is affected by someone typing on a keyboard or standing with one or more guests in the vicinity [64]. In designing or modifying technologies to be context-aware in outdoor, recreational, and educational settings like in the garden, how might we translate this concept of interruptibility? Attending to the location of a gardener and the meaning that they assign to different locations is a first step in estimating willingness to be approached. Our findings reveal how some areas in the garden are assigned significance based on the kinds of activities that take place. For example, a meditation hut would imply leaning towards solitude, whereas placing chairs together encourages interaction. Further, different configurations indicate an openness to interacting with different kinds of audiences, and whether activities take place inside or outside the garden fence has meaning. P2 arranging chairs to create a more intimate space for people inside the garden is intended for close communication with loved ones, whereas the benches outside the fence of P8's garden invite unknown outsiders to sit and observe. Gardeners' willingness to interact socially or use technology at all might be estimated from their locations within the garden and the configurations that they create over time and in the moment.

Even as we provide implications to avoid introducing technology in the garden due to its intrusiveness for some, others integrate certain types of technology into the gardening experience [27]. Expanding on past studies that find gardeners using technology to coordinate with garden members and showcase their ongoing activities (e.g., sharing photographs on blogs and social media) [4, 27], we find that gardeners also use technology to encourage involvement in the garden. For example, participants shared volunteering opportunities and recipes online. And, overall, gardeners reported positive interactions sharing garden-related content. They particularly appreciated receiving compliments. We see the sharing of gardening-related content as one way to support a sense of community and civic engagement. Here, further research might consider how sociality varies across different activities or types of interactions and how this relates to activities seen as social or purposeful, for learning or community building, and by different kinds of practitioners.

2.6.3 Negotiating Inclusion and Ownership

Past work has noted that inclusion is a core value of community gardeners [4, 55]. Our findings also reveal a desire for inclusion which is carefully balanced with gardeners' varying preferences for sociality. This was demonstrated through a physical configuration of gardens. The tension between the access to skills that experts can provide to novices and how novices can be excluded due to expert "territoriality" [54] is evident with the territory applying quite literally to the physical spaces of gardens. Below we discuss insights from our findings on how technology might affect the delicate balance between inclusion and ownership.

From our findings, we see opportunities where outsiders could come to interact in garden spaces to, for example, learn sustainable behaviors or create a sense of community by complimenting growers. Researchers can examine approaches that allow audiences to interact physically with gardening sites through location-based exploration concepts such as geocaching [66] or even citizen science approaches where people make data about physical spaces such as backyards, local parks, and other environmental observations accessible to the general public (e.g., Phenology Maps [67], NatureNet [68], and YardMap [69]). These approaches resonate with aims in the gardening space, such as learning when a specific plant species will bloom [67] or the environmental impact of personal growing practices [51]. When designing for public digitally-mediated interaction in the gardening space, it is necessary to think about how one might encourage the community to respect boundaries established by the inhabitants of the space. One approach might support gardeners in indicating that the local community is welcome to interact with certain elements or parts of the garden space (e.g., P1's flags for Independence Day) or inviting volunteers for particular tasks (e.g., P6's volunteers helping with weeding and harvesting produce). The metaphors of different kinds of fences and boundaries to promote or restrict visibility and access can inspire design in this area.

In our study, gardeners expressed a sense of ownership of the gardening space and the plants that they cultivate by establishing physical boundaries. Our findings also show examples of participants cultivating relations through their activities inside the gardening space around their native plants and other memory objects. What does it mean to design for inclusiveness in a living space whose inhabitants feel responsible for it, and when the objects inside the space hold meaning for the people or communities close to them? We propose that there are opportunities in HCI to support gardeners in highlighting and sharing the meaning that different objects or plants hold for them and their community. A current project that might be seen as falling in this design space is the Connected Seeds project which attempts to connect people to their heritage through food by collecting and sharing stories related to locally-grown seeds [52]. Further areas for connection we identify from our work include the concept of memory objects that reflect the gardener's relationship with a loved one, learning techniques for sustainable growing through observation, and experiencing different cultures (e.g., sharing produce native to the gardener's country).

An important aspect of inclusion is ensuring access for people with disabilities and mobility constraints – a priority mentioned by gardeners in our study. A fruitful future direction is to investigate technology's role in supporting accessible gardening. Research has in the past explored approaches to bringing the experience of a remote location through an on-site physical proxy to a user. For example, the Telegarden uses a robotic arm to interact with a remote shared garden such as in [70], and the Teletourism system provides accessible tourism experiences through a video chat with a video-sharer at the actual physical location that the viewer would like to experience [71]. This approach of virtually visiting a space might not be appealing when trying to communicate tacit knowledge that requires certain sensory stimuli (e.g., learning to determine the ripeness of produce via touch). Further, we propose that in addition to focusing on enjoyment, engagement, or immersion, as these prior systems do, it is important to think about how design in this space can position people and the kind of connections it can enable. For example, volunteers of different expertise levels connected with experienced gardeners P6, P7, and P9 in a community learning garden, where they worked with and learned from each other while contributing to the community's food security by donating produce. In other words, the garden is not just a space for recreation and connecting with nature –

it is also a meeting point for practitioners that provides opportunities to be good citizens. One area for future research might involve supporting experts who are no longer able to garden to remotely share their valuable skills with novices. This kind of approach could provide access to untapped expertise, a lack of which has posed challenges to previous projects [24]. In proposing this idea, we do not intend to minimize the real need to assess and improve the accessibility of outdoor spaces, a topic addressed in past work through crowdsourcing [72].

2.7 Conclusion

This paper contributes an understanding of how sociality is configured in the garden environment, and the ways that skill sharing takes place. Through our participant observations, we found that gardeners use and modify the boundaries of their gardens to maintain a balance between two considerations: the need for personal space for themselves, their co-gardeners, or loved ones, and a motivation to create an inclusive space in-and-around the garden and show community sentiment. Social skill sharing occurs between gardeners with a focus on on-site interactions that lead to learning. In addition to direct learning interactions, indirect learning takes place via observation of other people's gardens. We contribute a discussion of design considerations to support interactions for skill sharing between users with different expertise levels to support varying sociality preferences and in negotiating the tensions between community inclusion and ownership in the garden nature-space.

2.8 Acknowledgements

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Chapter 3: Probing the Potential of Extended Reality to Connect Experts and Novices in the Garden

3.1 Overview

In Study 1, I conducted participant observations with experienced gardeners to understand sociality in gardening and identify design considerations for skill sharing in gardening using collaborative technologies. The findings of this study motivated further examination of remote guidance approaches to address the need for access to expertise in instructional programs. For these approaches, the study also highlighted the importance of the embodied sensory experience of a physical garden, facilitating inspection of other's plots, and different social contexts involving family, the local community, and outsiders. Approaches using conventional video communication can be adequate for visual inspection. However, past HCI research has noted limitations in remote guidance involving physically manipulating objects and when conveying the desired embodied experience compared to more immersive approaches to guidance involving extended reality (XR).

In Study 2 of my dissertation, I examined the potential and limitations of XR to connect experts and novices for remote skill sharing in skilled hobby activities like gardening. As XR systems become increasingly available, XR-based remote instruction is being adopted for diverse purposes in professional settings such as surgery and field servicing. Hobbyists may similarly benefit from remote skill sharing. However, little is known about how XR technologies might support expert-novice collaboration for skilled hobby activities and how they might even be perceived for an informal hobby space. I had two objectives for my second study:

- Understanding practitioner perceptions of XR for remote skill sharing in the garden
- Identifying the types of interactions that can be supported in XR for expert-novice groups.

Study 2 had two parts that involved prototyping and feedback on prototype usability with 27 expert and novice gardeners. From my findings, I discuss design opportunities and challenges for XR systems in supporting informal connecting interactions and meaningful sensory interactions with a remote environment during skill sharing. This discussion also raises questions about how the remote environments (spaces and objects) are meaningfully represented in XR which provided the primary research direction for my subsequent Study 3.

This chapter is adapted from my paper on "Probing the Potential of Extended Reality to Connect Experts and Novices in the Garden" [9] published in the proceedings of the 25th ACM Conference On Computer-Supported Cooperative Work And Social Computing (CSCW '22). As the first author, I led the study design, data collection, analysis, and written and oral presentation of this work.[1]

3.2 Introduction

Extended reality (XR) is a technique that alters a person's perception of their environment through the addition of interactive computer graphics over their field of view [73]. It acts as an umbrella term for a continuum of technologies having different variations and compositions of real and digital objects in the user's view [74] and includes augmented, virtual, and mixed reality (AR/VR/MR). As the capabilities of XR devices improve, there has been a reinvigorated interest among CSCW researchers to understand how the affordances of XR can support remote collaboration between distributed workspaces. One practical application area that has seen increasing interest within the larger area of XR for remote collaboration involves augmenting remote professional assistance and training when performing skilled physical tasks (e.g., field servicing [1,75] and surgery [2,76,77]). Often, these systems are designed to improve learning outcomes over traditional video for expert-novice team scenarios, such as remote experts guiding novices in equipment repair or maintenance processes [78]. Prior work has presented remote expert XR systems for teaching other physical activities such as musical instruments [60] or movement training [79,80]. As inquiry in technology research and design expands outside of the professional workplace [81] into skilled hobbies [7,82–84], there is an opportunity to understand whether XR can similarly succeed in supporting remote collaboration in

[1] Co-authored by Dr. Andrew Irlitti and Dr. Amanda Lazar. Dr. Irlitti helped with feedback on framing the paper in the context of related work (sections 3.2, 3.3). Dr. Lazar provided feedback and suggestions throughout the project and paper write-up.

a skilled hobby setting. In contrast to professional settings, hobbyist settings possess differences that might affect the design of XR systems. Skilled hobby activities such as woodworking or needlecraft privilege the joys of production over the value of the product [85]. Further, hobbyist learning can focus more on learning a way of life associated with the activity as a form of serious leisure [86], rather than improving one's skill with an economic incentive in mind [87]. Other differences which may affect user needs and the design of XR guidance include social interaction, community history, the strictness of adherence to ethical standards, and if the adequacy of training is evaluated in an institutional manner [88]. HCI and CSCW researchers are laying the groundwork to understand how XR might support remote guidance in the skilled hobby setting. Considerations key for designing XR for this purpose are being uncovered, such as the ways that experts hone their craft [89, 90], the importance of relaying context for learning physical tasks [91], and perspectives on nurturing sensing capabilities and mentor-apprentice relations through technology [92, 93]. This paper examines how XR systems might fit into expert-novice collaboration for the skilled hobby of gardening. Past work cautions us about introducing digital tools into gardening, as they might interrupt a practitioner's immersion in nature. However, socio-technological approaches whose objective is augmenting existing learning interactions may be more acceptable [4, 28, 94]. Gardening is a particularly fruitful case with which to examine technologies to support learning. Informal social learning is key to gardening, with practitioners learning from others in community settings [95], as apprentices [4], and with family and friends [5, 14]. However, with deskilling in food production due to industrialization and mechanization [21], there can be a lack of local access to gardening knowledge which may challenge the implementation of gardening education [24]. Past research has called for further study on how technology might support education about food production [4]. Conventional video communication can be inadequate when supporting educational activities where practitioners physically manipulate physical objects [96]. XR systems have been well studied in research on remote expert instruction for physical tasks with established sequences of actions (e.g., equipment assembly [97], surgical procedures [98]). So, there is an opportunity to understand whether XR could be a suitable medium to deliver remote learning experiences to distributed gardeners in a hobbyist setting and when XR environments might actually augment informal learning experiences.

Our research examines the potential of XR technologies for skill sharing in the case of gardening. Our research seeks to answer the following research questions:

- What are the perceptions of practitioners regarding remote skill sharing in the garden?
- What interactions could be supported in XR for novice vs expert gardeners?
- To what degree might users benefit from using XR to collaborate in the garden?

To answer these questions, we conducted a two-part study with 27 gardeners. In Part 1, we used storyboards and experience prototypes to elicit participants' attitudes toward remote gardening and identify the types of interactions important to teaching and learning in the garden. From Part 1, we identified three types of expert-novice interactions: instructing, observing, and discussing. For Part 2, we created XR prototypes to support these three interaction types. We invited participants to use these XR prototypes in expert-novice pairs to further our understanding of perceptions of XR and how XR interactions can support or fail to support the key interactions identified in Part 1.

Our paper makes three contributions. First, we provide results from an exploratory study as to whether and how to design XR for skill sharing in hobby activities through a case study in the domain of gardening. We find that participants were open to remote skill sharing, particularly when there was a motivation such as the distance between practitioners. In terms of how to design XR for skill sharing, through participants' usage and reflection on our prototypes, we identify necessary affordances to support instructing, observing, and discussing in XR. For example, supporting orientation in the three-dimensional XR garden space and with the sun's position was key for observational interactions. Our second contribution is in identifying a key dimension for XR to support skilled hobby activities – connecting interactions – which have been less central in the professional settings where much of the prior work on XR for expert-novice skill sharing has been done. This interaction type involves the ways that practitioners connect personally or socially to the environment and individuals around them. Third, we discuss the merits and limitations of XR perceived by expert and novice gardeners for skill sharing. We discuss challenges and opportunities for the practitioners when inferring information or conveying the effects of their actions.

3.3 Related Work

Below, we discuss past work that studies XR for remote collaboration and instruction. We provide a general overview of perspectives on individual and social processes facilitating skill acquisition and specifically discuss existing teaching and learning practices among gardeners to help contextualize our study.

3.3.1 XR for Remote Collaboration and Instruction

Remote collaboration over physical tasks has long been a topic of interest to CSCW. Several studies have found collaboration between task participants for physical instruction to be more efficient in in-person settings compared with using conventional videoconferencing tools [99, 100]. In-person collaboration provides a shared visual space [101] with fewer constraints on how participants communicate through verbal or non-verbal cues (e.g., gestures and facial expressions), and simultaneously view and interact with objects in their physical surroundings (e.g., people, tools, or materials). Collaborative XR research has sought to understand how video communication can be augmented with better support for these in-person communication affordances (e.g., 3D embodiment through avatars) and also enable novel interaction methods going beyond the naturalistic in-person setting (e.g., viewing at multiple scales [102]).

One major focus of XR research has been to understand how embodied representations of remote collaborators that render their body movements onto an avatar can affect communication behavior in remote physical task scenarios. Viewing remote users in a shared visual space, for example, even as video avatars attached to movable cards [103] can result in a stronger sense of co-presence and personal understanding of the conversational relationships between participants compared with conventional video-conferencing. Embodied avatars (e.g., full-body or virtual hands) that enable gesture-based communication (e.g., deictics, metaphorical, or iconic gestures [104]) also help anticipate a remote collaborator's needs and result in comparable conversational and non-verbal communication behaviors to face-to-face interaction over non-embodied representations [105]. Researchers have also considered how sharing embodied emotional cues (e.g., facial expressions and heart rate) during remote collaboration and instruction can improve performance [106, 107]. Other interaction techniques include allowing remote users to draw annotations overlaid on a remote or shared virtual environment [108, 109], representing gaze [110, 111], representing the remote environment [112] and objects through 3D reconstruction or virtual replicas [97]. These techniques can allow for improved spatial referencing, over conventional videoconferencing, for instructions during remote guidance in embodied and non-embodied XR.

Specifically, for instruction-based scenarios, embodied practices are being supported in XR environments in a variety of domains [96]. This includes the design of XR systems better aligned with the informational needs of expert and novice surgeons during telementoring [76] and in industrial product design for remote collaborative modification of CAD models [113]. We also find examples of designing XR for teaching activities that may also take place in a hobbyist or informal social setting outside these professional or formal learning settings. Loki is an example of a remote-expert XR guidance system where different stages of learning (e.g., observation or collaborative review) can be supported by different configurations of interface elements for the teacher and learner (e.g., virtual or augmented physical environment) in example activities like learning musical instruments and sculpting [91]. However, learning scenarios are often presented in a manner that is agnostic to the nature of the learning context. The needs of experts and novices in professional settings [76] can differ from those in hobbyist settings. With the increasing pervasiveness of XR, in this paper, we discuss the challenges that can occur in the design and evaluation of remote XR systems for skill sharing in hobby settings.

3.3.2 Perspectives on Skill Acquisition

The process of skill acquisition through expert-novice interactions has been approached through multiple lenses in past work. It has been modeled in the past as a function of cognitive demands in different stages of learning [60, 91] for physical tasks, such as playing a musical instrument. For example, Fitts and Posner's three-stage model for physical learning describes an initial cognitive stage where the novice attempts to understand the requirements of physical movement through observation and discussion [114]. This is followed by an associative phase where the novice practices to retain effective actions, and finally, an autonomous phase where movements become fluid and largely automatic. Kolb [115] developed a theory of experiential learning where practitioners understand and process information in a four-stage cycle: concrete learning, reflective observation, abstract conceptualization, and active experimentation.

The above models focus on the cognitive process of acquiring skills as an individual. Learning is also viewed as enculturation into social processes. Lave and Wenger define communities of practice as groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly [3]. Novices in such communities learn through a gradual deepening of their participation in a community of practice. Experts mentor novices by demonstrating tasks and helping them as they perform the task by observing and coaching through a process of cognitive apprenticeship [116]. Researchers have employed this community of practice framing to understand how people at varying levels of experience or qualification collaborate remotely (e.g., on social networking sites for bodybuilding [117]). In the context of informal learning, James Paul Gee [118] defines "affinity spaces" that bring together people with different expertise levels to interact around a common passion (e.g., online games, cooking) in a common physical, virtual, or blended space. Participation and learning in affinity spaces are more flexible and less hierarchical than in communities of practice, and practitioners can share knowledge about the things they are more familiar with while learning from others who have more expertise.

Mutually establishing an awareness of shared knowledge and beliefs through testing and signaling, referred to as common ground [15], is important to form the connections required for collaboration and learning in communities of practice [119,120]. Olson and Olson's paper "Distance Matters" highlights the importance of high common ground and its positive influence on trust and effective collaboration in distributed groups [106]. While hobbyist learning is characterized by building communal common ground (e.g., by becoming aware of norms), building personal common ground by sharing personal beliefs and feelings can also be important, especially in contexts that involve friends or family [15]. Our work identifies different types of interactions key for expert-novice skill sharing, adding "connecting" with other practitioners and the activity environment in XR as a central dimension of guidance and establishing common ground in skilled hobby settings. We discuss how practitioners perceive XR supporting these interactions compared with conventional video or audio conferencing.

3.3.3 Teaching and Learning in the Garden

The technology design literature on food production often highlights broader motivations for individual practices, such as sustainability or addressing food insecurity. For example, a study of practitioners who routinely brew, preserve, and forage contributes to the notion of habitual engagement with food science as a sustainable practice that researchers should aim to support [121]. Interactions between experienced and newer practitioners are key opportunities for sharing knowledge and insights into local sustainable practices and fostering nuanced ethical decision-making [6]. Experimentation and observation are frequently mentioned as part of the learning process in gardening [5, 27]. In addition to individual activities that support learning, the social context plays a major role. Family and friends serve as trusted sources of information and as partners [5]. Face-to-face interaction with experts helps novice gardeners learn embodied and sensory skills such as measuring ripeness by touch and the safe handling of pruning shears [9]. Researchers have often discussed how design that introduces technology for learning into the garden should consider how gardeners build knowledge about natural processes and learn to observe and identify issues in the garden through sensory engagement (e.g., touch, smell) [6, 27, 121]. An example of a design that augments this engagement with nature is Liu et al.'s wearable hand-substrate interface for mushroom foragers to directly measure soil information and understand how environmental changes can affect the mushrooms in an embodied manner [45].

Perspectives on acceptance of digital tools by practitioners are often an important consideration when deciding to design or "not design" [35]. Handwork practitioners (e.g., knitters and gardeners) are often more forgiving of technology when it extends, interjects, or segments their activity in meaningful ways [27]. It isn't clear if XR could be considered unobtrusive for specific scenarios (e.g., distant family interactions) by gardeners. Previous work has identified socio-technological approaches supporting gardening education and outreach as a fruitful area of research [4, 28, 35]. For example, Heitlinger et al. call for researchers to disseminate knowledge about sustainable practices [4], doing so through co-designing with a diverse group of growers to share their stories combined with networked sensor data from their gardens [52]. Keeping this in mind, we present the perspectives of gardeners on accepting XR into the garden for the activity of remote skill sharing and, more generally, on the perceived merits and limitations of XR for this purpose.

3.4 Overview of Approach

To understand the considerations for XR when designing for skill sharing in the garden, we conducted a user-centered process through a two-part study. In the study, we used storyboards and experience prototypes (Part 1) and XR prototypes (Part 2) to (a) explore perceptions of XR and remote skill sharing in the garden, and (b) identify and understand whether XR might support the different types of interactions involved in skill sharing in the garden.

ID	*Expertise*	*Sex*	*Age*	*Ethnicity*
E1	Experienced	M	38	Indian
E2	Professional	F	33	White
E3	Professional	F	38	White
E4	Experienced	F	60	Caucasian
E5	Master Gardener	M	80	Caucasian
E6	Master Gardener	F	60	Caucasian
E7	Master Gardener	F	77	Caucasian
E8	Experienced	F	59	Caucasian
E9	Experienced	F	67	White
E10	Experienced	F	48	Hispanic
E11	Experienced	F	66	African American
E12	Experienced	F	72	African American
E13	Experienced	F	19	Mixed
E14	Experienced	M	21	Asian
E15	Professional	F	69	White
E16	Experienced	F	20	Mixed
E17	Experienced	F	21	White
E18	Experienced	F	21	White
E19	Experienced	F	23	White
E20	Experienced	M	22	Caucasian
E21	Experienced	F	22	White
E22	Experienced	F	18	Asian
E23	Professional	M	51	Hispanic
N1	Novice	F	24	White
N2	Novice	M	28	Caucasian
N3	Novice	F	20	Asian
N4	Novice	F	39	White
N5	Novice	M	26	Indian
N6	Novice	M	23	Black

Table 3.1: Self-Reported Participant Information.

All study procedures took place on the East Coast of the US over six months between mid-Spring and early Fall. Participants were recruited through fliers in

Session	*Participants*	*Relation*	*Study Part*	*Session Location*
S1[4]	E4	Friends	Part 1 (Storyboards)	E4's home garden
S2[4]	E2	Friends	Part 1 (Storyboards)	E2's community garden
S3	E5, E6, E7 E8, E9, E10	Neighbors	Part 1 (Storyboards)	E8 & E9's home gardens
S4	E7, N1	Friends	Part 1 (XP-2)	E7 & N1's home garden
S5	E11, E12	Friends	Part 1 (XP-1)	Community garden
S6	E3, E13	Colleagues	Part 2	E3's community garden
S7	E4, N2	Family	Part 2	E4's home garden
S8	E14, N3	Couple	Part 2	Reserved Indoor Space
S9	E15, N4	Colleagues	Part 2	Reserved Indoor Space
S10	E2, E16	Colleagues	Part 2[1]	E2's Office
S11	E17, E18	Friends	Part 2	Reserved Indoor Space
S12	E19, E20	Couple	Part 2	Reserved Indoor Space
S13	E1, N5	Unacquainted	Part 2	Reserved Indoor Space
S14	E21, E22	Acquaintances	Part 2	Reserved Indoor Space
S15	E23, N6	Colleagues	Part 2[1]	Reserved Indoor Space

Table 3.2: Session Information. [1]Due to time constraints, these participants were unable to evaluate the awareness prototype. [4]For sessions where we were unable to recruit a novice, the first author (a novice) partnered with the expert.

public areas, online posts, word of mouth, and snowball sampling. Recruitment materials called for people who regularly gardened, assisted with a garden, or were experienced gardeners. Participants were encouraged to involve relatives, friends, or a mentor they learned gardening skills from. Between the two parts, 27 individuals participated in the study (see Table 3.1 for participant demographics). We intentionally recruited a group that was diverse in age to match the demographics of this activity in naturalistic settings [14]. Participants ranged in age from 18 to 80.

Participants had varying self-reported expertise levels that include three master gardeners, four professionals, 14 experienced hobbyists, and six novices. In this study, individuals belonging to the experienced, master gardener[2], and professional[3] categories are referred to as "experts" labeled as E#, with novices labeled as N#.

[2]Master Gardeners are local county residents who receive extensive horticulture training and certification as part of university extension programs in the US. They commit to being volunteer partners by helping educate other residents to be better gardeners and improve their environmental stewardship. https://mastergardener.extension.org/ .

[3]Horticulture educators or researchers by profession. E2, E3, and E15 are professionals and also hold Master Gardener certification.

We note that while labeling participants as experts provides a convenient way of distinguishing them from inexperienced novices, there is nuance within this designation. Participants we termed experts often described themselves as a novice compared to others. There are significant relative differences in experience even between participants labeled similarly. For example, while one session (S3, see Table 3.2) involved 6 "experts" in that all participants had some experience gardening, the three master gardeners were considerably more knowledgeable than the others and served as experts with the other three gardeners acting more as novices. Our participants were all based in the US, so our insights reflect perceptions of US-based gardeners. The outdoor sessions in gardens, for Part 1, were also conducted during the summer and do not reflect seasonally dependent tasks.

3.5 Part 1: Exploratory Storyboards and Experience Prototypes

We designed two storyboards and two experience (XP) prototypes to identify attitudes toward XR technologies and to understand the types of interactions that are important to teaching and learning in the garden. To inform the design of storyboards and experience prototypes, we first identified the following design considerations from past work on interactive technologies in the garden:

- Sociality is a key consideration when designing for learning in the garden. Learning occurs in person by interacting with more experienced gardeners or even observing a neighbor's plot [4, 5, 28]. Learning to garden cultivates relationships with family, friends, and the local community [35]. Given these past findings, we set our prototypes in the context of social scenarios.

- Past work indicated the importance of the embodied sensory experience of a physical garden in teaching and learning [6, 27, 28]. Given the importance of on-site interaction with the garden for developing and teaching this skilled hobby, prototypes all have at least one individual in a physical garden site, rather than both parties having XR interactions with a virtual gardening site.

- Learning through visual inspection is an important part of developing gardening expertise [28]. Therefore, our prototypes involve scenarios where gardeners can see each other's gardening plots, not just the gardening task, to facilitate these learning interactions.

3.5.1 Prototypes

Below, we describe the storyboard and experience prototypes and the study procedures employed with each.

3.5.1.1 Storyboards

Storyboarding is a process of describing a user's interaction with a system through a series of images with a textual narrative [122]. We developed storyboards that depicted two uses of a "tele-garden kit" so that we could understand participant perceptions of different remote interaction scenarios using XR. We chose to use this tele-garden kit concept so that we could demonstrate XR features without requiring any technical explanations. The kit consisted of head-mounted "smart glasses" that each user in the storyboard wears. The XR features that the kit demonstrates include a 3D reconstruction of the gardening partner's remote environment as well as virtual tools for embodied demonstrations.

We designed the storyboards to differ in ways that would help us further understand participant perceptions of XR in the garden, specifically around how the relationship between users or the specifics of the gardening interaction might affect their attitudes. The first storyboard (Figure A.1 in Appendix A) depicts an informal collaborative gardening scenario, where an experienced and novice gardener have a preexisting relationship but live in different areas. The tele-garden kit enables them to garden "alongside" each other. This scenario centers on social bonds and interactions in an informal social setting. The second storyboard, in contrast, depicts an expert mentor scenario (Figure A.2 in Appendix A). An expert gardener who cannot work due to injury guides a novice through their garden. The smart glasses let the expert supervise the novice, as it shows what the novice is seeing and doing in the garden. This scenario centers on a more goal-oriented learning scenario, where the expert can demonstrate the actions required for tool usage so that the novice can tend to their garden. These differences in the storyboards led participants to talk about different types of interactions that included task-related teaching or learning as well as other kinds of skill sharing that appear in a more informal hobby setting.

Eight expert participants interacted with the storyboards over three sessions (see Table 3.2). Each 60-minute session had two parts: an initial group gardening session in the participants' garden followed by a semi-structured group interview. In the group gardening part of the session, the participants demonstrated instructional tasks for a novice, to provide a shared experience that could be referred to when discussing the ideas presented in the storyboards. Examples included soil preparation, transplanting, building supports using stakes, watering, weeding, and mulching the plots. During the semi-structured group interview, we showed participants the storyboards. Participants discussed their perceptions, including how their experience with the onsite activities in the initial part of the session might translate when using the tele-garden kit (a stand-in for an XR system) in the storyboards.

3.5.1.2 Experience Prototypes

Experience prototyping is a process used to understand, explore, or communicate what it might be like to engage first-hand with a system, space, or design concept (e.g., role-playing scenarios with or without props) without needing to build a full application [123]. Whereas the storyboards helped us understand participant perceptions of different remote interaction scenarios using XR, we conducted experience prototype sessions to understand how some aspects of XR might work in practice – specifically, how different configurations within XR (i.e., first-person or shared spatial context) might be used to support skill sharing. Experience prototypes have limitations involving factors that will not be present in the real application. For example, individuals were able to gain certain types of awareness due to being co-located that they could not if they were remote. However, they can still yield insights to inform our understanding of the design topic.

We designed the first prototype (XP-1) to examine how a remote expert might

Figure 3.1: Expert (on the right) using an iPad to observe video streaming from a GoPro mounted on the head of the novice. The image shown here is captured from that stream and shows the novice learning to use a tool.

use a first-person view, from the novice in the garden, to provide mentoring (Figure 3.1). Many XR systems in professional settings use real-time view-sharing from different perspectives to support remote guidance (see Section 3.3.1); XP-1 was motivated to understand how real-time view-sharing might be used in this hobby setting. Though the expert and novice were co-located for the study session, we simulated remote instruction by having the two participants in locations where they could not see each other. The novice wore a GoPro camera mounted to their head to generate the first-person video stream that was viewed by the expert on a tablet. We instructed the expert to guide the novice through a task over a video call in the experts' garden. We observed how the expert used the novice's point of view as they mentored the novice. Our second concept (XP-2) utilized a "virtual window" to examine how experts might teach in a shared spatial context in XR (Figure 3.2).

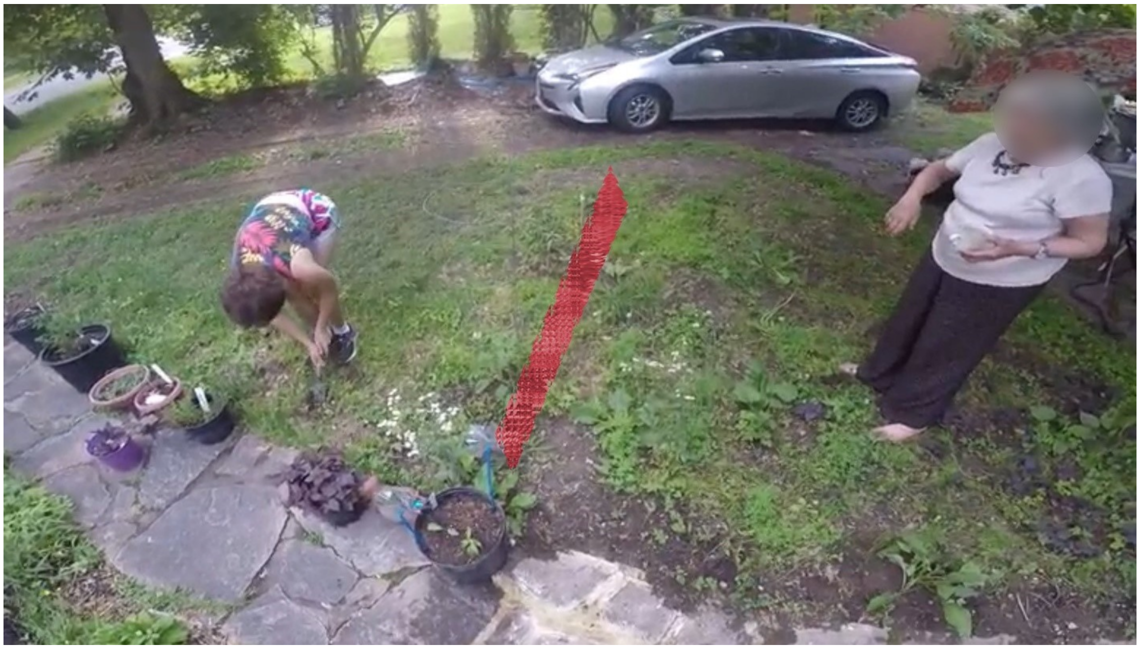

Figure 3.2: Expert instructs a novice transplanting a plant, separated by a virtual window (in red).

To simulate working remotely, the expert-novice pair were positioned in areas alongside one another in a garden representing two remote areas separated by a virtual boundary between them. The expert then imagined guiding the novice through a task across the virtual boundary by observing each other through a virtual window on the boundary. Identified as important in past work (see 4.1.1), this virtual boundary design allowed both the expert and novice to visualize working with an ideal XR system with 3D reconstructions of their remote partner and garden (visible through the virtual window) while noting potential challenges to the experience. It needs to be noted that the absence of a visual barrier for both XP-1 and XP-2 allowed participants to be reciprocally aware of each other's viewpoints to some extent. This could have affected their interpretation of working with the prototypes and required researchers to heed instances, for example, when participants involuntarily forgot role-playing as a remote user.

Four participants took part in the XP sessions, which lasted 60 minutes each. Before each XP session, the more experienced participants selected gardening tasks to guide the relatively inexperienced participant through. The tasks chosen were like those in the storyboard sessions and included soil prep, transplanting, watering, plot leveling, and layout planning. During the sessions, we observed how participants optimized teaching or learning given the constraints on their view, such as using gestures or changing their positions to get a better view of each other's actions. These observations structured the subsequent semi-structured interview, which lasted about 20 minutes.

3.5.2 Key Interactions Identified in Part 1: Instructing, Observing, and Discussing

Findings from this phase are discussed in depth in Section 3.7. Here, we describe three types of interactions that we identified as central to expert-novice interaction in the garden as these informed the design of XR prototypes in Part 2: instructing, observing, and discussing.

- *Instructing*: When instructing, experts describe and demonstrate how to do particular tasks. In doing so, they provide in-situ descriptions of sensory experiences. E4 broke up clumps of soil with her hands to give an example of what *"fine"* soil texture looked like to her during the initial group gardening session. Experts use their entire bodies as they instruct novices. Master gardeners E6 and E7 demonstrated a soil preparation technique while we observed. E6 used her hands to measure fertilizer, the spacing required between plants, and how high a plant would become. The novice plays an active role as well, mimicking the experts' actions when learning the technique or asking questions.

- *Observation*: Some kinds of observation are easier for novices to pick up. E2 described how a novice could learn to identify weeds, bugs, and if plants were growing well. Over time, an expert observes with a bigger picture in mind. Often, this bigger picture involved environmental impact. E5 looked at how a certain change, such as the growth of an invasive plant, might affect the local community across different levels. In terms of health – would the plant harbor dangerous pests? In terms of safety – would the plant pose a risk to passersby or cause structural damage to walls? Finally, E5 considered the broader environment – whether the plant would cause harm to local pollinators. This kind of ability to consider short and long-term consequences requires a familiarity with a specific garden and knowledge of local flora and fauna. It also requires an understanding of community history that is built over time and through interaction with other gardeners.

- *Discussion*: In contrast to instruction or observation, discussion-based interactions are less formal and more collaborative. Garden planning, for example by E11 and E12 on their shared plot, is one such discussion-based activity. Referring to themselves as artists, E7 and N1 spoke about creative ways of arranging plants with different colors, growth rates, and different heights. Though they act collaboratively, the expert draws on their expertise in this interaction, asking the right questions to ascertain the novice's preferences and describing possibilities in the gardening space in terms that the novice will understand. In instances of garden planning during the group observation part of three sessions, an expert (E4, E6, or E7) helped a relatively inexperienced partner (first author, E8, E10, or N1) visualize the spread, height, or color of plants and how that would affect the look of the garden over time. However, contributions and decisions, such as which plants to grow or how to arrange them, are made by both participants in these kinds of interactions.

These three types of interactions - instructing, observing, and discussing – and their related activities became the primary components around which we built our prototypes in Study 2.

3.6 Part 2: Development of XR Prototypes

Part 1 was designed to identify initial perceptions of remotely gardening together as well as interaction types that are important to remote expert-novice instruction. The objective of our second part was to assess how XR could support or be lacking when facilitating these interactions for novices versus experts from Part 1 (Section 3.5.2). To study this, we designed XR prototypes around each key interaction and evaluated them with expert-novice dyads. The sessions took place in a lab setting where the participant dyads accessed a virtual garden simulated using a 360 image through our XR prototypes to simulate a "real" garden for walking through scenarios. The scenarios were based on activities encountered frequently for the key interactions identified in Part 1. However, the participants were allowed to use the virtual garden in XR in an open-ended manner and were encouraged to think aloud, speak to each other, and ask questions in a way they might normally do during the scenario. A researcher was present with the dyad during the session to aid with using the prototypes and ensure participant safety in case of VR-related discomfort. Below, we describe the implementation of the XR prototypes for each of these activities. We also describe scenarios presented to participants to act out. Then, we describe the study design for the XR prototype evaluation.

3.6.1 Design and Technology Choices

We scoped and designed three prototypes from the key interactions (instruction, observation, and discussion) and their associated activities that we had identified in Part 1. We were motivated to understand how practitioners adapted to perform familiar activities, each focusing on one interaction type, in the virtual representation of the remote garden in XR. Our prototypes include an expert tour activity that features instructing, an activity to build awareness of the garden that features observing, and a garden planning activity featuring discussing. For each prototype, one participant wears a virtual reality head-mounted display, and the other experiences the first-person view and annotations made by the VR headset user through a tablet (Figure 3.6). This design choice was sufficient for us to better understand the impact of our previously highlighted interactions from Part 1.

- We focus on the interpersonal interactions between participants using first-person view-sharing as in recent remote-instruction systems [124]. This design also avoids participants focusing overly on the look or feel of an avatar, where prior research has already identified issues such as uncanny valley effects [125].

- To control for repeatable scenarios, a 360 image of a physical garden was used. A consistent virtual environment across participants let us compare the ways individuals interacted with the environment in a way that would not have been possible in a more naturalistic study design.

- Understanding the limitations of our design space, we selected activities such as drawing and pointing. These were suitable for gaining a broad view of perceptions and use of XR in a way that matches many informal hobby-levels needs relevant to our selected technology set-up.

All prototypes were developed in Unity for the Oculus Quest headset [71]. In all three prototypes, the user wearing the VR HMD is presented with a 360-degree static view of a garden. The first-person perspective of a participant wearing the HMD is shared with their partner on a tablet. We shared this view by screencasting over Wi-Fi using the Oculus mobile app and srcpy, an open-source software for Android devices. When Wi-Fi was unavailable, we used a tethered connection between devices. Although the XR prototypes were designed to simulate remote interaction, participants were co-located during the sessions to mitigate additional factors like bandwidth and audio transmission. This setup kept the focus on collecting user feedback on the interactions rather than technology limitations.

In the VR environment, the controllers for the VR HMD are visible to the participant as virtual hands. These prefabricated objects are provided by the developers of the Oculus Unity SDK. We used the default settings that take inputs such as button presses and represented them as virtual hand movements and gestures such as grasping and pointing. These movements and gestures were then mapped to different interactions within the virtual system. We detail the interaction elements available to the VR HMD user (assumed remote) along with the technique used to implement them in Table 3.3, using the categorizations suggested in prior work [28].

3.6.2 Activity 1 - Expert Tour

Scenario: An expert (assumed on-site) is guiding the remote novice through a familiar community garden while instructing them about the importance of key characteristics of the space and the activities that take place there (e.g., trellising or composting). The novice is encouraged to ask questions and moves with the expert between different viewing locations on a provided garden map by "teleporting" to different 360-degree scenes.

Prototype Description: This prototype (see Figure 3.3) is centered around the key interaction of instruction that we saw experts engage in Part 1 to support learning. The prototype provides an immersive setting in which the expert can answer questions posed by a novice gardener regarding plants, the environment, or practices that can benefit the larger community. The remote novice wears a VR HMD and can experience 360-degree viewpoints at various locations inside an

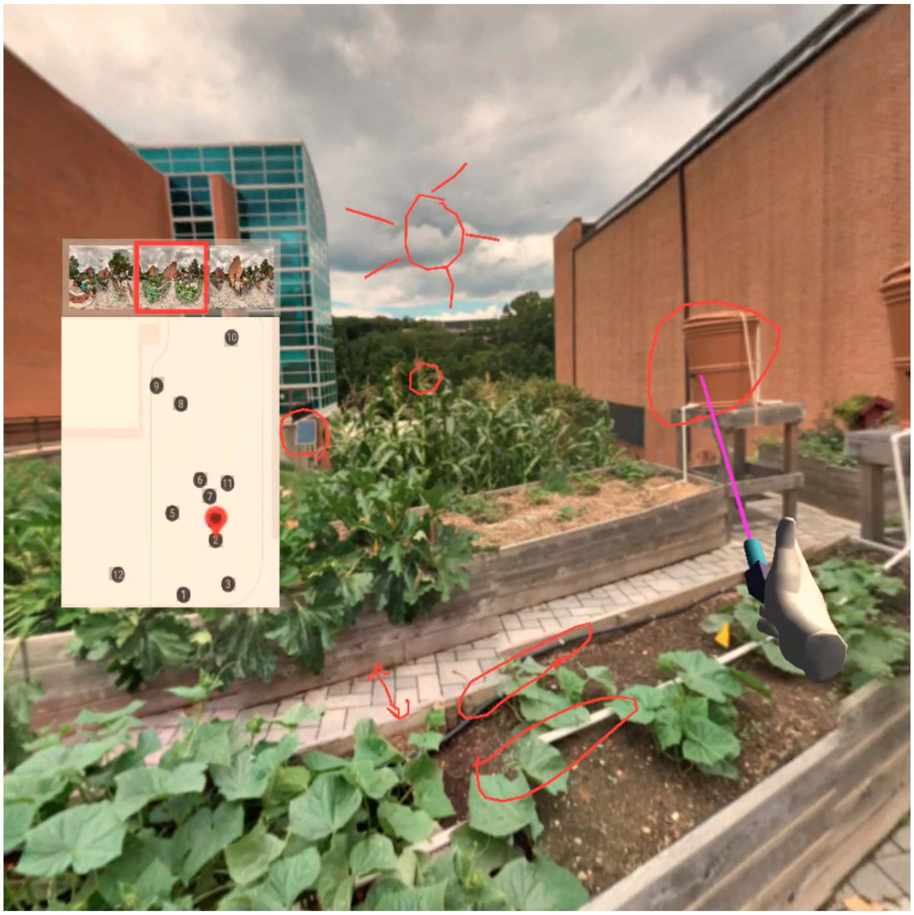

Figure 3.3: Expert Tour design probe screenshot. The novice can draw or point at objects or orient themselves with a map.

expert's garden. To support interaction with the environment and to get feedback when performing physical actions demonstrated by the expert (assumed on-site), as in Part 1's group gardening sessions, novices could use virtual hands linked to their controllers' movements. A drawing tool (Figure 3.3) allowed the novice to mark points and lines on the scene in VR to visually communicate areas of interest to the expert. The expert uses an AR device (tablet) to instruct the novice while also being able to view their XR-related actions (e.g., lines drawn or virtual hand movement) overlaid on their environment.

3.6.3 Activity 2 - Awareness Building

Scenario: The remote expert is going on a walk through the novice's garden to help them become more aware of the changes in their garden by describing what to pay attention to. They are pointing out elements that, in their experience, require inspection (e.g., weeding or plant health) but could be overlooked by the novice gardener (assumed on-site).

Figure 3.4: Awareness design probe screenshot showing how the novice can capture photos using the camera tool. The photos preserve a view of the environment for the novice to take note of and become aware of changes over time.

Prototype Description: This prototype (see Figure 3.4) is centered around the key interaction of observation. We learned in Part 1 that observational activities are led by the expert to identify objects or events in the garden to support a novice in building an awareness of the characteristics of the garden and its larger connection to the environment. In this prototype, the VR HMD is worn by the expert and depicts a 360-view of a garden. In Part 1, experts modeled thinking about the ways that elements in the garden change over time and discussed aspects of the garden that may be difficult to notice for a novice. To facilitate these interactions, we created a virtual camera so the expert could photograph elements in the scene as well as the ability for the expert to draw to "annotate" the environment. The camera and drawing features provide a way for the expert to detail their process of observation by taking snapshots of elements in the garden that may change over time. The novice uses an AR device (tablet) to view these annotations provided by the expert overlaid on their environment.

3.6.4 Activity 3 - Collaborative Garden Planning

Scenario: The remote expert is giving the novice (assumed on-site) guidance on how to plan a plot in their garden remotely. The expert looks around and also asks the novice for some information that they might need about the plot (e.g., soil type) to provide better guidance. The expert also marks some areas on the plot with the drawing and planting tools to visualize things and get the novice's opinion.

Prototype Description: We built the garden planning prototype (see Figure 3.5) as an instance of a discussion-based activity. Planning the layout of a garden is

Figure 3.5: Garden Planning design probe screenshot. In dialogue with the novice, the expert selects a plant to place in the plot or draws garden boundaries.

a creative activity that both the expert and novice can discuss and collaborate on, while also drawing on expert experience (e.g., related to plant placement). For this prototype, the remote expert wearing a VR HMD can view a 360-view of an empty plot from the novice's garden. During planning sessions in Part 1, participants sometimes visualized a specific plant at a position and marked positions or areas by drawing lines, laying thread, or other objects in the garden. Therefore, we facilitated the expert in using the controller and grasping a virtual spade to "plant" three types of virtual plants (sunflowers, tomatoes, and jalapenos) as well as a drawing tool to sketch a garden layout. These interactions could support, for example, deciding the optimal aesthetic and functional placement of plants and visualizing the growth of different varieties. The novice (assumed on-site) uses an AR device (tablet) to see the expert's annotations in XR overlaid on their plot.

Figure 3.6: Experienced gardener E14 (viewing the laptop) and novice gardener N3 (wearing the Oculus HMD) dyad from session S8.

3.6.5 Evaluation of XR Prototypes

In Part 2, expert-novice dyads evaluated the three XR prototypes in 60-minute sessions. Each session was audio-recorded with the researcher simultaneously taking observation notes and photographs. In each session, participants used all three prototypes, with one participant wearing the VR HMD and the other using the tablet/mobile to see the other person's point of view (Figure 3.6) — whether the novice or expert wore the VR HMD depended on the prototype (See Table 3.3). The participants then spent 15 minutes working through each example activity and were

Prototype	*Remote User (VR HMD)*	*Local User (AR Tablet)*	*Tools for Remote User with VR headset (Implemented Technique)*
Expert Tour (Instruction)	Novice	Expert	**Virtual Hands** to support novice with interaction with the environment and to get feedback on physical actions. **Drawing Tool** to allow the remote novice to visually communicate areas of interest to the expert (ray casting with hand controllers). **Teleportation** for novice to "move around the garden" (using controller buttons)
Building Awareness (Observation)	Expert	Novice	**Virtual Camera** for an expert to take snapshots of elements that may change over time. **Drawing Tool** for an expert to annotate the 360 scenes and detail their process of observation. Virtual Hands
Garden Planning (Discussion)	Expert	Novice	**3D Plant Models** for an expert to help visualize a specific plant during planning. **Drawing Tool** for an expert to mark positions or layouts in the scene. Virtual Hands

Table 3.3: Summary of interaction elements for the remote user of XR prototypes in Study 2.

asked questions that compared using these prototypes to their current approaches for those activities. We recruited 10 dyads of gardeners, where the more experienced gardeners played the role of the expert in the dyads. The views for the expert tour and awareness-building prototypes were captured at a local community garden that all experts and novices (except N2) had visited at least once before the study session. The view for the garden planning prototype was captured at a community garden that was unfamiliar to all participants (except E4). The 360-degree images were generated by using the Google Street View mobile application and an iPhone 6S.

3.7 Analysis

Our data included a total of 14 hours of video recordings from interviews and dyad interactions during prototype usage and researcher observation notes from each session. To understand the perspectives of experts and novices on their needs and expectations around using XR, we selected a qualitative analysis approach. Specifically, we followed the thematic analysis approach outlined by Braun and Clarke [126] that has been in past HCI research to allow for a deeper social interpretation of data, for example, by highlighting similarities and differences across user perspectives which can inform the design of interactive systems [127]. First, the first author transcribed the audio from the recordings for further familiarization with the data. For both Part 1 and Part 2, two transcripts and two sets of observation notes were open-coded by the first author to create a preliminary set of codes and emerging themes. Examples of initial codes included "comparison with in-person teaching," "taking a closer look at a remote object," and "helping the novice visualize". The first author then coded the rest of the transcribed interviews with these preliminary codes, adding additional codes as they emerged while searching for themes. The research team then reviewed and further defined the themes.

Below, we present our findings on three salient themes. First, we discuss perceptions of XR and remote skill sharing in the garden. Then, we discuss how the prototypes support, or fail to support, key expert-novice interactions (instruction, observation, discussion). Finally, we identify connecting as an important dimension when designing for skill sharing in hobby activities.

3.7.1 Perspectives on Remote Gardening

Here, we detail practitioner perceptions of XR and remote skill sharing.

3.7.1.1 Hesitant but Open to Remote Instruction in the Garden

As we engaged participants in discussion using our prototypes, we learned their first impressions of the idea of gardening together remotely using technology. Some participants were initially hesitant to consider *"digital stuff mixing with garden"* (E6) as in-person interaction was a pleasure and privilege: *"We're connected to the gardens we are all part of it and to put the technology in there ... it's interesting and could be helpful to people that live far away and don't have anyone to help them person-to-person ... but for us, we have the pleasure of being with each other."* In Part 2, E21 talked about the value of having immediate feedback from *"a real person"* in an on-site interaction but also recognized *"that would be the highest level of interaction"*. As the above quotes indicate, participants recognized the utility of connecting remotely when it was not possible to garden together in person. They discussed cases such as being separated by distance or mobility issues, such as the gardener with the broken leg in Storyboard 2. Two participants (E2 and E8) shared past positive experiences with remote collaborative or instructional gardening. E2's partner had instructed students on a farm through FaceTime in tasks such as troubleshooting machinery, and E8 often learned gardening techniques over videoconferencing from her mother who lived in a different country. Participants E6 and E7 became more receptive to the idea of *"digital stuff"* and XR after listening to E9 talk about video chatting with her relatives from her garden.

For some, however, unfamiliarity with XR may pose a lingering barrier. After using the XR prototypes in Part 2, E15 felt that she might have been more comfortable with guiding someone remotely *"if we had a computer screen."* She explains that *"part of that may be just getting used to the tools [the headsets and controllers for the XR prototypes] because it's totally foreign to me."* Unfamiliarity with using XR didn't however affect E21's positive views about the utility of using the prototypes for remote guidance. He described that they were *"a nice kind of leeway between the pure video that's totally not able to have feedback and the master gardener that would be there, present [on-site]"*.

3.7.1.2 Necessity for XR Depends on Type and Complexity of Task and Novice Characteristics

Many participants explained that, when using the prototypes, the streaming video that we used as a proxy for a 3D headset gave adequate information to engage in skill sharing for certain tasks. E11 explained how she could determine the richness of the compost by observing visual cues such as color and the way *"it was falling over"* during the remote video call in XP-1. E7 found the first-person view of the novice to be appropriate when using XP-1 (video call prototype) for instructional tasks where the expert E7 was *"directing it myself"* and telling the novice *"exactly what to do"*. In session S10, E4 after using the prototypes describes that *"the beauty to me of the VR is that you can take some actions"* (e.g., selecting and planting 3D models of plants). However, for some tasks, XR was not sufficient. E2 described several activities that require *"physical presence."* "You really need to feel it" to measure soil moisture and you really need to be able to *"tug at it [the roots] ...*

see how pliable it is" to determine if roots were established. And E7 explained the necessity of demonstrating the activity in the local context to get a better sense of how to instruct: *"I can't really explain to someone how to do it because I don't know until I actually put my hands down there"*.

In this way, the specifics and complexity of the embodied interactions required in different tasks were noted as factors that make XR more or less suitable. Expert participants also considered the characteristics of the task, as well as the novice's skill in determining whether verbal instruction could work without the need for the novice to see the experts demonstrating actions, for example, with an AR overlay. They shared the perspective that verbal instruction based on the novice's view alone was sufficient when the risk to the garden from a mistake was minimal, and when the novice had more experience. Yet, even though participants described verbal instruction as sufficient in some instances, we saw them acting in ways that belied this sentiment during our sessions. E11 and E12 explicitly said they were able to properly communicate how to use a tool using verbal cues in XP-1, but E12 still tried to demonstrate a more optimal way of using a digging tool by holding and working with it. As seen in this anecdote, though experts found ways to effectively verbalize instructions, embodied demonstrations may yield additional benefits or feel more natural.

3.7.2 Skill Sharing Interactions Using the XR Prototypes

Here we describe findings on how the prototypes from Part 1 and Part 2 supported or lacked in their capability to facilitate the key interactions we described in Section 3.5.2.

3.7.2.1 Instructing Using an XR system.

Participants used their bodies as part of the instructional process in almost every Part 2 session, across each XR prototype. Participants took advantage of the interactive capabilities we had built to point, place plants, capture photos, and draw during the activities. Individuals saw the ability to point and place virtual plants, hold a virtual spade tool, or pull examples from a library of virtual objects as a good starting point for teaching simple tasks. When demonstrating was not possible using these XR prototypes, experts tried to instruct novices using sensory descriptions. E17, for example, suggests that E18 should give the tomatoes in the XR view *"a gentle pull and if it comes off easily then it's ripe"*. However, articulating subjectively interpretable instructions, such as being *"gentle"* (E2, E4, and E17), was challenging.

Overall, participants described feeling mostly positive about the potential to instruct in a remote garden through an XR system. However, experts emphasized aspects of the XR prototypes that needed improvement: *"really specific details"* related to techniques that a novice would not necessarily be aware of but an expert would notice. For example, considering spacing on the horizontal plane through the 360-view was possible and useful for planning plants in a garden. However, visualizing depth for the novice was not properly supported, so it was not possible to show how deep to plant something. E4 tried to hold a plant and pat down the soil with the virtual hands, something that was not supported in the system. The XR prototypes were also less flexible than tools used in in-person demonstrations and were designed based on some assumptions by the first author. Expert horticulturist E15 shared that she couldn't demonstrate using the virtual spade tool in our XR prototypes since it was made for men: *"We have different muscle sets and different ways of using our body."* This example highlights how experiencing the virtual tools and environment in Part 2 led participants to more deeply consider their ability to instruct in XR and the complexity of designing digital tools.

3.7.2.2 Observing and Understanding the Remote Garden

Like how they engaged onsite, experts in the virtual environment tried to observe the land, sky, and garden surroundings to glean information and communicated the importance of noticing this information to novices. Experts used the affordances of the XR prototypes to make these observations, and their actions indicated additional ways XR might be designed to support observation in ways that are key for skill sharing.

We learned that orientation was a key activity for participants exploring the remote garden environment in XR. Individuals drew on the affordances of the XR environment and verbal communication to better map the remote environment and consequently provide better guidance. One way this occurred was by orienting themselves with the position and trajectory of the sun. The first action performed by experts in all nine garden planning sessions (S6 to S14) of Part 2 was looking at the sky in the virtual environment to determine the location of the sun. Participants tried tracing an imagined trajectory of the sun over time to envision shade patterns (E21). The remote experts used these assessments and their estimation of possible sources of shade such as trees and virtual plants, to estimate whether a plot would *"get a lot of morning sun, was it going to get a lot of afternoon sun"* (E17). They then used this understanding to aid the novice in planning their garden. Experts also attempted to orient themselves within the garden space in the XR prototypes. The remote user would often request that the user in the virtual garden verbally indicate the cardinal directions so that they could orient themselves in the 360-degree view, to increase their ability to observe and explore the garden space. Related to this need for orientation, two participants suggested including a *"compass"* tool in the application (E2 and E4). In other cases, participants would orient themselves by describing objects in the view of the XR-environment (e.g., *"there is another marker-like thing to your left."* (N5)).

Another aspect of orienting to the remote space involved understanding how the XR environment affected participants' ability to make subjective measurements and decisions. An example was how their ability to *"just sort of eyeball"* or measure by sight was affected, with E2 mentioning that she adjusted by guessing distances and the scale of objects in the VR environment by using familiar objects like *"six-inch pots"*. Participants in every session tried to engage in actions to obtain better observations of their environment in ways that were not supported by the XR prototypes. Participants tried to gather information from the remote environment by moving closer to an object of interest, for example, when observations were limited by the visual quality of the static environment. They described wanting to look at more minute details like the hidden underside of leaves to check for signs of bug damage (S8 and S13) and to check for fruits that may have ripened under the foliage (S6 and S9). E3 talked about the potential for the user in the garden to help make measurements on behalf of the remote user. These included experts interacting with the novice in the garden and asking them to *"move here, pick it up or like I said, focus on a flower"* (E21), even suggesting being able to *"zoom in more"* (E4) when trying to identify unfamiliar plants together using visual features like leaf shape or flower type. These findings indicate how collaboration in the dyads was important for orienting the remote practitioner to the remote garden in XR.

In addition to visual indicators, participants described certain kinds of observations that were best done utilizing other senses, such as determining ripeness by smell or touch and measuring soil type and moisture by feel rather than just relying on visual indicators. These interactions were appreciated for their necessity in instruction, as well as aesthetics, but also to develop *"more of a coherent idea of the garden as an ecosystem"* (N4) as a novice. Participants noted sounds that were lacking such as birds and insects and smells such as basil and earth. The *"static"*(E3) nature of our VR environment, even with our attempt to design an application to support noticing changes over time, was seen as insufficient for supporting the visualization of changes over time. A *"time-lapse"* (N2) or application that could *"move you through time"* (E15) was suggested as useful to assess spatiotemporal trends, such as by allowing the gardeners to envision a spring garden in the Fall. These findings bring to the fore the dynamic nature of the garden space, and the challenges, and opportunities that this raises for XR environments.

3.7.2.3 Discussion Between the Practitioners

Discussions between the participants often involved making decisions together based on both the expert and novice's inputs. In Part 1, we saw examples of this during garden planning activities, as in E6 and E8's discussions. E6 proposed replacing a certain plant to which E8 suggested something that her neighbor had planted and *"won the beautification contest in [locality]"*. The expert would sometimes draw on their greater awareness of the environment to suggest options to the novice. E6 and E5 recommended plants native to the locality based on E10's choice of an aesthetically pleasing color for her front yard. Being able to see each other when on-site was viewed as more valuable for discussion-based activities. As mentioned in Section 3.7.1.2, the first-person view of the novice was seen as appropriate for tasks where the expert was more of an instructor, rather than collaboratively discussing and deciding together. In session S4, E7 referred to the second experience prototype and said she could have designed her garden with N1 better using the XP-2 (virtual window) prototype as they could be *"actually looking together at the ground looking at the seed packets and talking back and forth."* Further, there were important social cues key for discussion-type interactions: E19 talks about how having access to facial expressions and other *"subtle body language"*, as in onsite interactions, would help understand if the novice had any questions.

Yet, some aspects of the environment we built were useful for discussion-based activities. Participants said that constructing 3D visuals with the drawing tool (e.g., E21 creating cages around plants) and virtual plants (e.g., E14 and N4 working out space availability) and possibly having a library of such virtual objects (E15) helped provide visual aids for these interactions. This was helpful even if the participants did not feel that the virtual objects fit what they were trying to visualize. For example, E21 mentions the small size of the virtual plants didn't exactly fit the age of the plants he was trying to help N6 visualize.

3.7.3 Connecting Interactions and Emotional Dimensions

Above we discuss the way the three interactions we identified in Part 1 were or were not supported in XR. Here, we discuss a finding that emerged once we had completed both parts of the study: an additional interaction type that appears to be key for hobby skill sharing. In this section, we describe the personal and social dimensions of connecting interactions between practitioners in the garden space, as well as participants' thoughts on using XR to support or enhance this kind of interaction for remote sessions. From a personal perspective, practitioners valued connecting to their environment through independently growing food, gaining awareness of their impact on the environment, and engaging in recreation. Positive emotions percolate into the way that participants talked about their garden: making the soil and plants *"happy,"* feeling creative and refreshed in the garden, caring for the garden as a space that is alive, and being mindful and attending to changes over time. Spaces like the garden connect people with nature and each other. E7 spoke about *"a spirit"* when onsite in the garden space, *"that's guiding us and it gives us our questions and answers and creativity. You can feel it, you can smell it, you can hear it and everybody is a part of it."* Expert-novice groups in Parts 1 and 2 were often relatives, friends, or acquaintances, which created an informal atmosphere in the sessions. Participants expressed emotion and expressed bonds with one another while enjoying their beloved activity together with family, friends, and other gardeners. Participants like E3 found the sessions to be *"fun because E13 and I are friends and know each other too."* Being able to converse with one another during the task, share stories about their experiences, learn together, and work with each other contributed to the enjoyment of the activities.

Individuals used gardening to strengthen or contribute to their connections with others by considering and accommodating each other's needs. When working with XR prototypes, participants' discussions frequently revolved around each other's likes and dislikes and even the preferences of other loved ones. Experts helped novices plan their gardens differently based on whether *"my girlfriend really likes sunflowers,"* (E18) or if the novice wanted to *"grow them (tomatoes) and then cook food."* These findings indicate an important affective dimension to skill sharing. Practitioners valued each other's personal experiences with the gardening space and regularly connected through sharing stories (e.g., E6 *"struggling for years"* to grow a lily). They supported one another in creating personal connections to their environment by sharing observations they had made over time about the specifics of their local environments. E5 talked about how *"it was beautiful 50 years ago"* and that the *"unique environment"* of the community had changed over time due to *"all this agriculture... our lawn sprays... golf courses"*. As indicated above, connecting interactions took place across all three of the other types: observing, discussing, and instructing. From the above findings, we see that connecting interactions is an important part of the social experience of working together and learning in the garden space. Our discussions with participants revealed opposing views on whether the XR prototypes could support or even augment the dimension of connecting. Being able to see a hologram of the remote person in a third-person view, as in the storyboards and XP-2 of Part 1, rather than just a first-person view, was one of the points discussed. Many of the participants in Part 1 of the study found this feature of being able to work alongside the hologram of the remote person in XR appealing, particularly when building or enhancing a social relationship through gardening activities, such as with distant family members. When compared with regular video chat, this feature also seemed to indicate the potential for more intimate communication. E8 describes how in her interactions with her mother *"I would feel more close with her through this than I would [over] Facetime."* However, despite the system being preferred over alternative communication platforms, E2 mentions that it wasn't as easy to share sensory aspects compared to when in-person. The prototypes would simply not be *"the same as having them in-person and being able to hug them and hold them and smell them"*. She suggested supporting a way to *"pick some things and share them somehow"* as a remote feature that could provide a meaningful interaction that replicated in-person exchanges. This kind of meaningful interaction appeared organically in Part 2, with E14 trying to share a virtual flower across realities from VR into the *"real world"* with his girlfriend N3 during garden planning in session S8, as well as in other sessions (S6, S7, and S10). This possibility of picking something unique from the garden with your own hands and virtually sharing it with a remote user seemed to differentiate connecting with XR from conventional video chat. Participants also mention working with virtual models of objects familiar to them, like *"my trowel, and I'd want the bucket"* (E15) or their own *"watering can"* (N3 and E4) that could provide visual aids and augment the sense of connection to the virtual environment.

Finally, we observed that the sessions in Part 1 yielded more instances of participants connecting with other gardeners, by sharing past personal experiences with the activity, than in Part 2. This might have been due to the sessions taking place in participants' own physical gardens in Part 1 rather than in a virtual one that they might not be as familiar with. Familiarity with the setting, as E14 describes, allows one to talk more intimately about how *"this is why I put this here."* The choice of displaying the first-person view of a remote practitioner for the XR prototypes, as mentioned earlier in Section 3.7.1.2 and 3.7.2.3, might have also caused participants to tend to instruct and observe more compared to discussing and connecting.

3.8 Discussion

Through a two-part study with 27 gardeners, we sought to understand how remote skill sharing might be supported using XR in informal, hobby settings. In our discussion, we focus on two areas. First, we review the merits and limitations of XR perceived by expert and novice gardeners for skill sharing. We discuss how XR can create challenges and opportunities for practitioners when inferring information or conveying the effects of their actions in an XR representation of a remote garden. Second, we present a synthesis of our findings on personal and social connecting dimensions of design for XR as they relate to building common ground in an informal hobbyist setting. We discuss design opportunities and challenges for supporting connection during remote skill sharing.

3.8.1 Merits and Limitations of XR for Remote Skill Sharing in the Garden

Perceptions around merits and limitations of XR for skill sharing in the garden were strongly tied to how it interacts with the practitioner's sensory experience and the social setting, as in findings for other digital tools in past works [35, 36]. Our findings reveal that practitioners view the utility of remote skill sharing positively when in-person gardening was not feasible. In other words, if they have opportunities to share skills in-person in the garden, they will likely choose this. However, if they lack nearby practitioners with expertise, as in [24], or have specific distant loved ones whom they would like to garden with, remote skill sharing may be useful. Remote XR could provide different challenges and opportunities for experts and novices when supporting the key interactions of instruction, observation, discussion, and connection. One of the challenges affecting the experts stemmed from the limitations on sensory engagement in the remote environment using XR. Experts in the garden often measured in an embodied manner, by feeling with their body or just by sight, and used the resulting qualitative assessments to communicate their observational or instructional process to novices. We found the remote expert participants for our prototypes compensating for this by using a couple of approaches: by relying on visual cues (e.g., soil color for moisture) and, more successfully by directing the local user to explore the space on behalf of the remote user. However, as our participants note in Section 3.7.1.1, these can be easily accomplished via just video communication. Interaction frameworks for remote guidance in past works, like Kasahara et. al's Ghost-Body framework [128] and Gauglitz et. al [129], have extended conventional video chat by allowing the remote user to independently explore and annotate a reconstructed 3D space from the local user's view. Based on our findings, the ability to observe by independently orienting oneself to explore and annotate the activity space could be viewed as a merit for XR by a remote expert or novice. On the other hand, we find that gardeners are often trying to better notice details (e.g., leaf underside) that are minuscule compared to the size of the activity space or even hidden. For this purpose, collaboration with the onsite partner to perform hands-on actions in the garden, for example, to get a better view might be just as easily performed over conventional video chat. It is also debatable whether simulating the in-person sensory experience for a remote user through a non-visual output device (e.g., a haptic actuator for texture [130]) is an approach that might add value for instruction through XR for either an expert or a novice. Given our participants' perceptions of experiencing nature in an almost spiritual way through gardening, we are inclined to disagree. However, once again, the specific social setting and the sensory stimuli being rendered remotely may be a factor in this. There has been past work that proposes a case for mediated social human touch and how it might benefit *"togetherness"* for scenarios involving preexisting relationships [131, 132]. In an informal hobbyist setting, would it even be necessary to add precision to an XR environment by digitally mediating the missing sensory information purely for better instruction or observation? Do experts or novices in this setting care about that level of precision? We found there was some robustness to mistakes built into learning in the garden depending on task complexity and when gaining expertise as a novice can be more important than the quality of the result. Errors can also be valuable events, leading experts to connect with the novice by sharing their thoughts on a space that they view as being alive and to be cared for. In these examples, the interactions between the expert and novice that result from errors might positively influence skill sharing. So, it is important to consider what errors might mean for the practitioner in this setting. Some of the more explicit merits of XR are related to shared discussion and observation interactions visualizing time and seasonality. Instructional, collaborative, observational, and discussion activities that involve the passage of time, reflecting on the past, or envisioning the future are particularly suited for XR applications – leading to an opportunity to connect with work investigating the use of XR for visualizations [133]. For example, participants attempted to describe the movement of the sun over time from east to west of the plot when planning where to plant something. Participants also wanted to teach novices to recognize signs of damage by specific pests by simulating this over time on the virtual models of plants in the garden planning activity from Part 2 of the study. The ability to orient oneself and move one's head to trace the sun through the sky, or to move closer and interact with a plant are key characteristics that would differentiate these cases from what is possible with simulations that don't use XR.

3.8.2 Building Common Ground Through Connecting Interactions in XR

When designing to support skilled hobby activities, we posit that personal and social connecting dimensions must be central in informing system design. We identified connecting interactions between our participants that seem to be important when building communal and personal common ground [15]. In the communal sense, we find connecting interactions included sharing motivations, and describing their influence on their local environment through their actions in the garden space. These seemed intended, by both experts and novices, to inspire a sense of belonging to a local gardening community. More informally, our participants also described the personal significance of certain objects in their garden and how these added to relationships with friends, or family (e.g., using produce to cook). We find similar interactions in the backdrop of collaboration and instruction in other gardening studies [4,5,27,28] and other hobbyist communities such as in makerspaces and DIY cultures where artifacts can be created to drive discussion and reflection [22, 134]. While onsite interaction for this purpose with physical artifacts is viewed as the ideal case in these studies, our findings also indicated that XR has the potential to augment remote connecting interactions between practitioners that build common ground for a more intimate learning experience when compared with conventional video or audio methods. Leveraging familiarity is an important consideration for representing spaces and objects in XR compellingly to support connecting interactions for a specific hobbyist group. Participants in our study appear to have been more comfortable remembering and sharing stories (e.g., why they decided to grow something) in the familiar context of their own garden in Part 1 when compared with the relatively less familiar setting of the XR prototypes in Part 2. Leveraging familiarity in this context can mean highlighting familiar sights and amplifying sounds such as those of birds and insects in the background to trigger conversations around the local ecosystem, as suggested in one of our sessions. In this way, augmenting practitioners' ability to use their physical activity space and artifacts to remotely share stories specific to their local context seems a promising approach for XR over other remote methods. This local context can include the history of the community and changes in the local environment over the years that local practitioners might be more familiar with and can convey to a remote novice. Building common ground in XR during connecting interactions relies on more than just representing a familiar space and objects in it. Participants should have ways to meaningfully express communal or personal significance. An example to drive this point is the importance of sharing or gifting artifacts in informal hobby settings. Practitioners cultivate relationships with loved ones by sharing produce from their gardens [28] or by gifting a hand-knit sweater [27]. One area of future research is to understand how in-person, material interactions compare to sharing interactions using 3D virtual objects. In addition to comparing these mediums, it is worth investigating how the 3D environment might lead to additional affordances for making familiar remote objects shareable and interactable virtually (e.g., arranging or reshaping together), for example, with a *"memory object"* [28] that holds personal meaning in the garden. Given that learning in gardening is often an intergenerational activity [14], there is an opportunity to leverage past work, such as digitalizing physical mementos for intergenerational storytelling [135] or creating a 'magical' experience that triggers meaningful memories through remote XR augmented spaces [136]. A fruitful direction suggested by our findings is to understand how to better facilitate sharing stories that convey multiple different viewpoints of a group of local practitioners. Another key consideration in creating compelling representation in XR is that practitioner perspectives on the need for realism in remote interactions varied depending on the task and actors involved. Participant perceptions of whether XR could support connection were influenced by the sensory realism of interactions with the remote environment, including smell, touch, and sounds. For objects and artifacts, the need for realism seems to vary depending on the type of interaction they were being used for. We find supporting "connecting" interactions to be different from the other instruction-focused interactions we identified where participants consistently tended to prefer realism. In those cases of learning interactions, for example, experts discussed the importance of the design of virtual spades or other tools to account for physiological differences when instructing in an embodied XR system (e.g., tools for different body types). On the other hand, for connecting interactions, all participants who used our XR prototypes, regardless of expertise, described being able to perform the action of sharing virtual flowers as more important than the realism of the flowers. Whereas the objects or actions used to connect can be abstracted, in some cases participants expressed that social partners in connecting interactions should be represented more realistically. When discussing working alongside remote users as in the storyboard and XP sessions, participants expected realistic full-body holograms of their loved ones. They described or attempted to engage in activities such as hugging and sharing. These are unique instances of realism vs abstraction debate [137] where participants emphasize the in-person experience of a sensory-rich and dynamic activity but leave room to debate the extent of realism that is necessary to feel connected.

3.9 Limitations

This study has several limitations. First, the XR prototypes for Part 2 did not have a physically implemented augmented or mixed reality component (AR/MR) for the local user in the garden and used a 360-image virtual garden to simulate this. We noted significant variability during Part 1 in internet connectivity and found that outdoor lighting conditions negatively affected our VR HMD's tracking capability. Considering these challenges in an outdoor environment with changing conditions, an AR/MR interface would have allowed a more in-depth understanding of the effects of differing views and interaction with the environment on skill sharing interactions. Evaluations for more complex tasks such as displacing soil to perform planting, and longer-term observational studies of gardeners using an XR system in a more open-ended exploration are also warranted. Understanding the role of avatar representation in such tasks is also an important consideration that we did not fully explore in our XR prototypes. Second, configuring our experience prototype sessions with an explicit barrier, such as an opaque screen for XP-1 or a visible window boundary for XP-2, would have helped limit peripheral awareness among the collocated participants and allowed role-playing the remote scenarios more faithfully. In our findings, we have reported one instance of in-situ switching for XP-1 between focusing on the prototype and instructing as if side-by-side which, though it can be considered a data point, could have been avoided. Third, although our study does include novices and "relative novices", our recruitment text might have unintentionally encouraged more participation from active gardeners with some experience. As a result, our findings might be limited in reflecting the experiences of novices who have never gardened before.

3.10 Conclusions

This work examined the potential of extended reality (XR) for remote instruction in skilled hobby activities such as gardening. Past work on supporting remote instruction with expert-novice dyads using XR has largely focused on professional settings. Through a two-part study, we worked with 27 practitioners to understand how XR technology might support skill sharing in the informal setting of a garden. We find that compared to professional settings, it is key to consider the personal and social dimensions of connecting to build common ground with other practitioners and one's environment. It is also important to facilitate meaningful sensory interactions in a remote environment. Our research highlights opportunities as well as perceived challenges in designing to connect practitioners and support their ability to understand the dynamic sensory environment of the garden through XR.

3.11 Acknowledgements

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Chapter 4: Understanding Context to Capture when Reconstructing Meaningful Spaces for Remote Instruction and Connecting in XR

4.1 Overview

The sensory and social context surrounding objects in the garden is a recurring theme in my findings from the previous studies. In Study 1, I describe this context for the physical garden space and how that could inform social interactions during skill sharing on-site. In Study 2, I discussed how this context could inform the design of remote XR systems for teaching and for augmenting connecting interactions in an informal hobby setting. In this chapter, I present my final study that dives deeper into capturing this meaningful social and sensory context for the virtual representation of remote physical spaces and objects in an XR environment.

Recent technological advances are enabling HCI researchers to explore interaction possibilities for remote XR collaboration using high-fidelity reconstructions of physical activity spaces. However, the process of reconstruction often lacks user involvement with an overt focus on capturing sensory context that does not necessarily augment an informal social experience. In my third study, I sought to understand social context that can be important for reconstruction to enable XR applications for informal instructional scenarios. My study involved the evaluation of an XR remote guidance prototype by eight intergenerational groups of closely related gardeners using reconstructions of personally meaningful spaces in their gardens. My findings contextualize physical objects and areas with various motivations related to gardening and detail perceptions of XR that might affect the use of reconstructions for remote interaction. I discuss implications for user involvement to create reconstructions that better translate real-world experience, encourage reflection, incorporate privacy considerations, and preserve shared experiences with XR as a medium for informal intergenerational activities.

This chapter is adapted from my paper on "Understanding Context to Capture when Reconstructing Meaningful Spaces for Remote Instruction and Connecting in XR" [10]. It was published and awarded the best paper at the 2023 ACM SIGCHI Conference on Human Factors in Computing Systems[1]. As the first author, I led the study design, data collection, analysis, and written and oral presentation of this work.

4.2 Introduction

XR has seen increasing research and commercial interest as a medium to augment remote collaboration. When compared with traditional 2D media, XR provides a more effective way for users to perform spatial referencing and demonstrate ac-

[1] My co-author, Dr. Amanda Lazar, provided feedback and suggestions throughout the project and paper write-up. An independent researcher, Vibhav Nanda, assisted with gathering literature references for intergenerational XR (section 4.3.2).

tions remotely [97]. This can especially be helpful during collaboration and expert guidance for physical tasks in professional settings (e.g., surgical training [2, 76, 77], field servicing [1]). The increasing access to XR devices is also leading to a growing body of HCI work on system building and interaction design for informal settings with remote friends and family. These works can involve, for example, games [138], learning [139], and other general-purpose telepresence applications [112, 140]. Virtual representation of the users, their surrounding physical spaces, and objects in XR is an important element of this interaction design for collaboration or instruction. Recent advances in creating high-fidelity 3D environment [141, 142] and avatar reconstructions [143, 144] for XR devices are allowing remote collaborators to explore and obtain better spatial and semantic information from a remote environment.

The HCI community has explored various modes of representing real environments and objects as 3D models in XR to improve collaboration in remote guidance tasks [91, 145, 146]. These systems often focus on representing the activity space based on the constraints of the technology and designers' understanding of activity-specific interactions that need to be supported for guidance. For example, some objects might be explicitly prioritized for the demands of the activity by system designers during 3D reconstruction (e.g., high fidelity hand pose reconstruction during surgery [147]). In other works, often with room/table scale remote XR systems, the entire room/table volume and its objects are reconstructed by default [112]. There is also a focus on understanding how to create sensory affordances for the reconstructions comparable to their physical counterparts [148, 149] (e.g., tactile sensations for virtual surfaces [130]). This can be useful for activities requiring precise sensory input for skilled physical tasks (e.g., cutting through material for surgery). This designer-led approach of creating virtual representations of activity spaces by capturing activity and sensory context might be optimal for professional settings with standardized practices. However, informal activities with friends or family can take place in settings where the virtual representation of spaces and objects in XR needs to capture a more personalized meaningful context. Affordances for virtual objects that enhance social connectedness between group members through "connecting" interactions (e.g., sharing virtual replicas) can be a priority to aid remote informal collaboration by building common ground [15, 120]. But there is a missing understanding of how designers can translate the social context of real physical objects to their virtual representations and how this translation might affect user experience. Our work aims to better explore and understand this social context, in terms of expected social affordances, behaviors, and interactions, which reconstructed spaces and objects need to capture to be meaningful, for example, when connecting with a remote loved one. We take the case of hobby instruction in a closely related group (e.g., family, friends) of practitioners as an example of an informal setting for XR with the following research questions in mind:

RQ1: What is the important social and sensory context that can influence informal XR users' remote experiences with virtual representations of real activity spaces and objects?

A. What context is important to users for learning experiences with reconstructed spaces and objects?

B. What context is important for connecting interactions with reconstructed meaningful spaces and objects?

C. What context is important to users when sharing reconstructed meaningful spaces and objects?

RQ2: What are some design considerations for XR to support the values and goals of an informal intergenerational group interacting with the virtual representations?

We choose gardening as an example hobby where social interaction for instruction or connection is often intergenerational, community or family-oriented [5, 14] thus providing a rich context for physical spaces and objects associated with the activity. Although there are varying perspectives on technology inclusion in the space, socio-technological approaches for practitioners to learn from others have been suggested as a fruitful research direction in the past [4–6, 28]. We conducted a study with eight groups of 18 intergenerational participants to evaluate an XR prototype for remote instruction scenarios in gardening. Our prototype allowed participants to view and interact with pre-created 3D models of meaningful real areas and objects chosen by them from their gardens. This allowed us to identify the context that could be important for the models to augment instructional or connecting interactions over XR.

Our paper makes four contributions. First, we discuss if 3D models of a real activity space in XR can better support meaningful reflection during remote instruction (RQ1A). We note possibilities for reflection with different approaches to capturing context and constraints on using real-world experience to understand the reconstructed spaces. Second, we provide an understanding of the context that can capture social relations and emotional context (RQ1B). We discuss the value of virtual reconstructions to preserve shared memories and as mementos compared to physical artifacts. Third, we discuss potential spatial privacy considerations for the process of creation and social sharing of virtual reconstructions (RQ1C). Finally, we discuss how our findings on creating and sharing virtual reconstructions of physical objects and spaces could apply to other intergenerational activities and provide meaningful directions to explore when designing informal or casual XR (RQ2).

4.3 Related Work

4.3.1 Virtual Representation of Physical Spaces and Objects for Remote Guidance in XR (RQ1)

Past work on remote guidance in XR has covered virtual environment representations that include live or pre-captured 360-camera media [9, 124, 150], live or pre-rendered 3D reconstructions [76, 91, 112, 146], and using virtual proxies for objects [97, 151] in the environment. The design considerations that are highlighted in these works are often related to the relation between user experience and the context (e.g., visual features, physical manipulability) that is captured by different virtual representations.

4.3.1.1 Context Prioritized When Virtually Representing Real Environments

Previous HCI research on reconstructing the user's physical location as a virtual environment has predominantly focused on an understanding of the sensory context for reconstruction. This includes capturing and matching sensory context in terms of physical affordances (e.g., tactile sensations) of virtual objects with those of actual objects in the VR user's environment [148, 149]. This can help the user with safe navigability while wearing a headset, and for experiencing interactive and sensory-realistic virtual objects and proxies remotely. For example, the bumpy surface of a rock can be approximated using a vibrotactile actuator [130]). This matching of affordances of the virtual reconstruction or proxy with their physical counterpart is an important design consideration for the psychological feeling of presence in a remote environment and maintaining sensory coherence with the physical environment around the user when exploring a mixed reality environment [152] (e.g., have similar tactile sensation [153]).

Researchers have also proposed abstracted virtual proxies by capturing a set of affordances (e.g., hand manipulability [97, 107]) as a context that is convenient for the user's intended tasks. Radu et. al [107] provide an example of virtual proxies for virtual makerspaces that could capture context such as sensor data from their physical onsite counterparts, a model of their physical interactivity, and even discuss controlling these physical objects remotely through their proxies. There has also been substantial past research and re-emerging interest in commercial XR on creating 3D digital twins of environments or systems that can act as simulation proxies for evaluation and even educational tools for their physical counterparts (e.g., rockets, classrooms, and theatres) [140, 154–156]. Design work using XR for cultural heritage preservation has focused on instructional affordances of virtually reconstructed objects (e.g., 3D scans of museum artifacts [157]) and digital twins of historic sites [158–160] and how they could engage the learner to consider their meaning. For researchers and even a general audience, it can allow them to construct historical narratives by viewing and interacting with artifacts from all over the world in a single virtual "place" [161].

Commercial availability and capabilities of VR devices have increasingly improved for casual users. However, there is still a gap in current literature in a user-centered understanding of context beyond sensory features that is needed to create meaningful reconstructions for informal settings. A growing body of work has proposed understanding social context, in addition to sensory context, when interacting in XR with virtual representations of real environments in informal settings [9, 136, 162]. Maddali et. al suggests investigating how an XR environment might lead to additional affordances by making meaningful physical objects shareable and interactable virtually (e.g., arranging or reshaping together) and enable affective "connecting" interactions in hobby learning settings [9]. Based on their analysis, we argue that it is important to understand the breadth of social affordances for virtual objects in XR that enable connecting interactions, in addition to instructional (e.g., building observation skills), and physical affordances (e.g., being graspable). Our work provides a glimpse into what could be a meaningful social context for 3D models of real spaces in informal learning scenarios. We also discuss approaches to capturing this social context for XR.

4.3.1.2 Designer-Led Versus User-Centeredness in Identifying Meaningful Context for Virtual Representation

Virtual representation of real objects that can be used as physical props in a collocated interaction is important for remote instruction and collaboration scenarios [112]. We find that past works that use virtual proxies of physical objects in XR to explore remote interaction workflows [97, 112, 163] often use a designer-led understanding of context to create the proxies. In room-scale telepresence it is assumed that all the objects in the room are reconstructed by default [112]. Some works include pre-created [151] or live [164] virtual proxies of objects important for instruction. The presentation of proxies can also be prioritized based on importance to instruction (e.g., higher hand resolution for remote surgery guidance [165]). However, these works do not discuss/utilize any structured user-centered approach to identifying the objects and the surrounding sensory and social context that needs to be represented in XR (e.g., incorporating privacy preferences). Our work extends this space by identifying affordances for reconstructed spaces that arise when meaningful objects and spaces are intentionally selected with participant involvement. While we do find work that explores the privacy of person [140, 166], the privacy of space and the concerns of the user when creating or sharing reconstructed objects or environments are rarely discussed. Wang et. al point out the importance of acknowledging such concerns when users create and share 3D reconstructed moments [162]. We add to this XR-privacy literature by looking at context-dependent concerns and perceptions around creating and sharing virtual reconstructions of environments. We also present how the nature of the activity might influence how context is captured for the reconstructed models.

4.3.2 Intergenerational XR for Meaningful Informal Settings (RQ2)

HCI researchers have often contextualized designing remote intergenerational systems within a trend of increasing social isolation due to several factors like the dispersed and nuclear distribution of families [167]. In groups involving older adult users, the focus has been on use cases that combine gaming in some form with storytelling [168–170]. Game-based approaches have some benefits, for example, as a way to combine light exercise with social interaction [171–173]. However, among older adults, there might be a wariness of prototypes and game-like activities that could be perceived as children's activities or unproductive [174]. We see some HCI researchers taking this into account by avoiding associations with gaming when prototyping for intergenerational experiences or during study procedures [175]. This consideration also seems to be important when the objective for using XR is an exchange of knowledge, for example, of traditional culture between older and younger users [176]. Positioning older adults as keepers of family history and younger people as memory triggers [169] for intergenerational storytelling and reminiscence applications [169, 177, 178] has seen a positive user reception in past studies. However, these studies used traditional 2D media and objects. Our findings provide an understanding of how experiences with 3D models of real places and objects in XR would be perceived relatively.

Established industry players like Microsoft [112] have shown visions of using 3D reconstructions of real spaces for casual XR outside workspaces. Meta has notably implied intergenerational use-cases for XR telepresence where you could watch sports *"together from a 3D model of his dad's apartment"* [179]. However compelling use cases, outside of gaming, for a more diverse demographic of casual users remains to be implemented and adopted. To expand to a use-case that might fit a different set of interests, we chose a popular activity linked to leisure and informal learning especially as a hobby activity in an intergenerational setting [9,28]. Gardening has a highly multigenerational demographic with older adults (65 years and above) being the largest age group [14] and the most active volunteer group at extension master gardener programs [180]. In this work, we discuss intergenerational perceptions of social connection in XR around hobby learning as a meaningfully perceived use case. We link these perceptions with experiences of interacting with 3D models of real spaces and the context that they should capture. Past work has also noted that prototypes and use cases for XR can often be biased by a younger user and designer-centric approach [181, 182]. This can result in an experience asymmetry [11] for one of the age groups. In our study, we note how this, and other factors could have affected perceptions of the state of XR and its future possibilities for intergenerational interaction.

4.4 Study Description

4.4.1 Participants

We recruited a total of 18 participants (avg. older adult age = 69.7, avg young adult age = 45.8, avg teen age = 14 years) (Table 4.1) and conducted eight sessions (Table 4.2) of our user study with six pairs and two groups of 3 participants. The pairs and groups included older adults (aged 65 and above), and family members, friends, or acquaintances who were at least one generation apart (e.g., P6 was a friend of P5's daughter) with an average age difference of 31.5 years. 13 participants described memories of learning hands-on in the garden with their family by spending *"summers with my aunt (P1), and my grandmother"* (P2) or great-grandmother in P17's case. In four sessions (S1, S2, S4, and S7), younger participants' childhood experience with gardening was in the presence of their older study partners. Beyond leisure, it was a necessary skill for P6 who *"couldn't afford (veggies) to eat, so we had to plant (gardens) to eat"*. A few others (P5, P10, P12, and P17) described teaching themselves later in life through online resources or professional programs while encouraging other young members of their family to help in the garden (P12). P7 (younger) and P10 (older) had been kindling their interest in gardening outdoors with the help of their study partners. This qualitative and quantitative profile of our participants allowed us to collect rich data on the intergenerational social experience with our prototype. In all the pairs or groups, there was a significant, self-described difference between the members in their level of experience with gardening. Participants included four novices, 5 certified master gardeners, 5 experienced gardeners, and 3 "professionals" who were farmers (P3) and academics in agriculture and biology-related fields (P6 and P14). However, even here, experience between participants should be considered relatively. For example, P8 had substantial experience with farming compared to P7, and P15 was considered more knowledgeable than P14 who was a professional. The older participants were not necessarily the more experienced gardeners. For example, P1, P5, and P10 were either novices or less experienced than their study partners. This diversity in experience levels allowed us to collect feedback for our prototype from an instructional perspective.

ID	*Expertise*	*Age*	*Sex*	*Ethnicity*	*Participant Relations*	*Prior XR usage*
P1	Experienced	65	F	African American	P1 is P2's Aunt	Yes
P2	Master Gardener a	54	F	African American		None
P3	Professional b	74	F	White	P3 is P4's Grandmother	None
P4	Experienced	15	F	White		Yes
P5	Master Gardener	70	F	White	Good friends through P5's Daughter	None
P6	Professional	34	F	White		Yes
P7	Experienced	70	F	African American		None
P8	Experienced a	74	M	African American	P8 is P7's Husband.	None
P9	Novice	41	F	African American		Yes
P10	Novice	67	F	African American	P10 is P11's Mother	None
P11	Master Gardener	45	M	African American		None
P12	Master Gardener	67	F	African American	P12 is P13's Mother-in-law.	None
P13	Novice	39	F	African American		Yes
P14	Professional	54	M	Latino	P15 is P14 and P16's Neighbor. P14 is P16's Father.	Yes
P15	Experienced	69	F	White		None
P16	Novice	13	F	Latina		None
P17	Novice	54	F	White	Good friends and former neighbors	None
P18	Experienced	71	F	White		None

Table 4.1: Self-Reported Participant Information

In two of the sessions (S3 and S4), participants were in different cities/states and were truly remote. For the other sessions, we simulated a remote setting by having the participants in separate locations (e.g., a participant in the house and their partner in the garden). In four sessions, all remote/simulated-remote group members were familiar with the garden locations chosen for the study and reconstructions since they visited the location frequently. P6 mentioned having a general overview of the location for session S3 but never having been inside it. In session S4, P7 and P8 mentioned being introduced to P9's backyard only before the study over video chat. Only two sessions involved one group member viewing the selected garden location for the very first time (P13 in session S6, and P15 in session S7).

ID	*Participants*	*Walkthrough location(s) (Session Part 1)*	*Site familiar to participants*	*Session type*	*Models created (Session Part 2)*
S1	P1, P2	P2's home garden	Yes	Simulated remote[1]	P2's backyard and decorative area in front yard
S2	P3, P4	Family farm	Yes	Simulated remote[1]	Unplanted farm plot and decorative area
S3	P5, P6	P5's home garden	No (P6)	Remote[2]	Fenced area with garden beds in P5's backyard
S4	P7, P8, P9	P9's backyard, P7 and P8's home garden	No (P7 and P8)	Remote[3]	Unplanted garden bed in P9's backyard
S5	P10, P11	P11's home garden	Yes	Simulated remote[1]	Two unplanted garden beds and herb garden
S6	P12, P13	P12's community garden	No (P13)	Simulated remote[1]	Herb garden, butterfly garden, and memorial area
S7	P14, P15, P16	P14's community garden	No (P15)	Simulated remote[1]	Raised bed area, terraced slope, and bee house
S8	P17, P18	P18's home garden	Yes	Simulated remote[1]	P17's house garden bed, P18's back and front yards, and P17's comfrey plant at P18's house

Table 4.2: Session Information. [1]Participants alternated between mobile phones (for onsite AR) and Oculus Quest headsets (when simulating remote VR). [2]P5 on Tablet (AR) and P6 on VR headset. [3]P7 and P8 on mobile, P9 on VR headset.

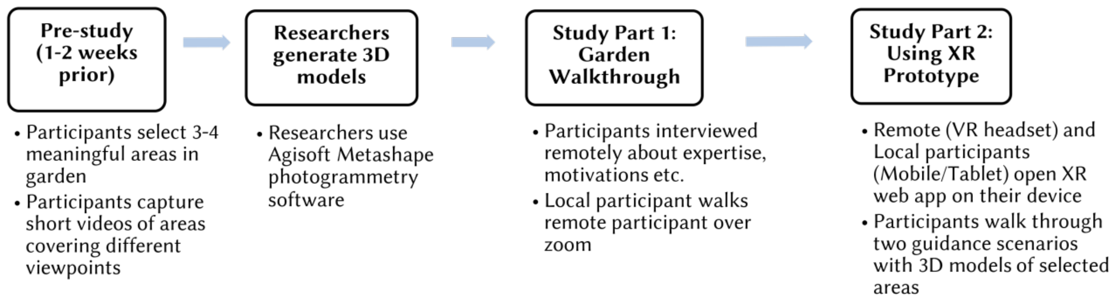


Figure 4.1: Summarized timeline for each participant session.

4.4.2 Procedures

Each session was 90 minutes in duration and had two parts following the timeline in Figure 4.1. The onsite participants walked the researcher and the remote participants through a garden area preselected by them over video chat in Part 1. This was followed by participants evaluating the XR remote instruction prototype in the expert or novice's garden in Part 2. A short pre-study session was also conducted either remotely or via email instructions where videos and photos from the selected garden site were collected by the participants or by the researcher with participant guidance. These were used to create 3D models of areas and objects in the participants' garden to be used in Part 2 of the study.

4.4.2.1 Pre-Study Session

Around 1-2 weeks before each session, the participants were instructed to choose 3-4 small areas (around 10ft by 10ft) in their garden that could be meaningful or interesting for them and/or their partners. These were areas that could be more familiar to them, have some objects/plants/features that they could use to

(a) P12 showing P13 some herbs that she might like to cook with.

(b) P4 walking through a plot that she helps P3 with.

(c) P5 showing P6 some artwork her neighbor made for their garden.

Figure 4.2: Examples of meaningful objects and areas discussed during the garden walkthrough. Participants focused on objects that might be meaningful for their utility in activities they like, instructional value, aesthetic reasons, etc.

teach something, or just might be enjoyable to be in. For each of these areas, the participants started capturing a 1-3 minute video by standing just outside the area and then doing a slow walk around its boundary while keeping the camera pointed toward the center till coming back to the starting location. During the walk, the participants were suggested to 1) keep their camera movements smooth and slow to avoid motion blur, 2) try ensuring the camera's view is unobstructed by, for example, a fence or tree and, 3) occasionally vary height and distance of the camera from the area to get a more comprehensive view of the area/object. An example video shot following these instructions was provided to the participants as a reference for the kind of video to be created. The researchers sampled the video frames and used 100-300 frames to generate each 3D reconstructed area/object using the Agisoft Metashape photogrammetry software [183].

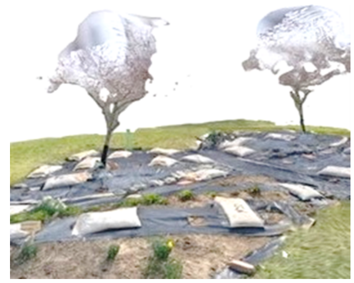
(a) Decorative area in P2's front yard (49K triangles)

(b) Decorative area in P3's farm (80K triangles)

(c) Garden bed in P5's backyard (73K triangles)

(d) Garden bed in P9's backyard (50K triangles)

(e) Herb greenhouse in P11's backyard (106K triangles)



(f) Butterfly garden in P12's community garden (1.05 Million triangles)

(g) Bee house in P14's community garden (83K triangles)

(h) Garden bed in P17's front yard (396K triangles)

Figure 4.3: One 3D model from the set of 3-4 models generated for each of the eight study sessions. Models were generated from video clips provided by participants of garden areas and objects they selected to be useful for instruction or meaningful in some sense. The scale of these ranged between large areas (e.g., butterfly garden) and small garden beds or single objects (e.g., herb greenhouse).

4.4.2.2 Part 1: Remote Garden Walkthrough Session

In this part of the study, participants were first interviewed about their experience level, familiarity with the pre-selected garden area and objects, and motivations for gardening individually and together (if done in the past). They then explored and conversed about the pre-selected garden areas and objects using conventional video chat as though they were remote from each other (in simulated remote sessions). The participants identified components of those physical garden areas that were meaningful to them individually and collectively (Figure 4.2) and gave us a sense of how these components could be utilized by them for instruction or to feel connected. This session also helped establish a shared gardening experience that the participants could refer to compare their social experience with the XR prototype in Part 2. This approach was also intended to be useful for the participants to reflect on the idea of remote instruction during the gardening session and provide them with a baseline for interaction using conventional video communication.

4.4.2.3 Part 2: XR Prototype Evaluation

On completing the remote garden walkthrough, participants evaluated an XR remote instruction prototype informed by design considerations and scenarios for garden planning identified from past work [9]. The objective of this part of our sessions was to understand how the objects and areas from the practitioner's activity space, identified through the pre-study session, can be represented and even augmented with meaningful context for instructional and social connecting interactions in XR. The prototype provided examples of virtual objects and environmental elements in XR that can be used by the practitioner for instructional or connecting interactions. Prototype usage was followed by a semi-structured group interview with the expert-novice group to help evaluate the prototype.

4.4.3 XR Remote Instruction Prototype

Our XR prototype is a multi-user system through which participants could interact as a group with the photogrammetrically generated 3D models of pre-selected areas and objects from their garden spaces and gain familiarity with XR environments. It is an HTML and JavaScript-based web app using the networked A-FRAME [105] package. Networked A-Frame uses WebRTC and WebSocket connections for audio-visuals and syncing remote users. Users can simply open a link to the prototype website on a browser in their mobile/tablet/VR headset, like a Zoom meeting link. By default, A-FRAME creates buttons on the browser UI to toggle between AR, VR, or in-browser modes. This allowed participants to use devices that were immediately accessible without restricting them to headsets for AR/VR. It also addressed health concerns around sharing headsets with other groups in the current COVID pandemic. In our sessions, participants onsite in the garden used the prototype in AR mode on a mobile/tablet and remote (or simulated remote) participants used the VR mode with the Oculus headset.

We used two scenarios appearing in past work [9] as evaluation scenarios for the prototype that illustrate instructional and connecting interactions in XR for gardening. In these scenarios, the onsite participant uses the AR mode of our prototype on their device, a tablet or mobile phone, to view a 3D reconstruction of the terrain of the garden. The remote participant views the model using the Oculus Quest headset in VR mode. In the simulated remote setting, participants played both the onsite and remote roles alternately.

4.4.3.1 Scenario 1 - Gauging Slope To Visualize the Flow of Water

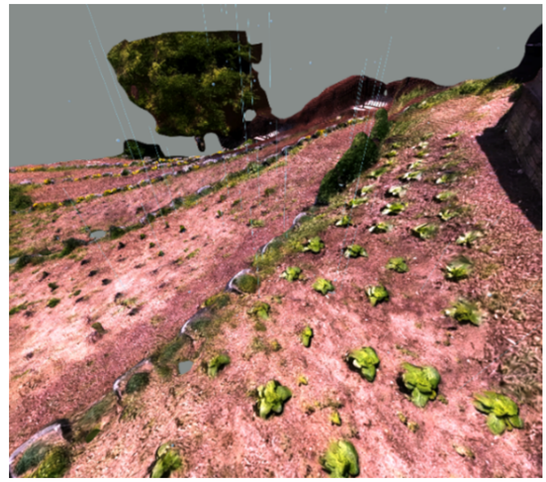
In this scenario, participants simulate rain on the 3D reconstructed plot using a rain particle system developed with an AFRAME physics library. This simulation will be visible on both the onsite participant's AR view and the remote user's VR view as a visual aid. Using this visual aid, an experienced gardener can talk a novice through planning a garden based on the flow of water on the plot (Figure 4.4b).

4.4.3.2 Scenario 2 - Visualizing the Distribution of Sunlight

Participants simulate the movement of the sun over the garden by moving a spherical light source and adjusting the virtual east-to-west axis in VR to align it relative to the physical plot. This can be used by an experienced gardener to highlight how the movement of the sun might affect the distribution of light on the plot over time. The web app simulates the lighting and shadows on the 3D reconstructed plot in both the novice's AR view as well as the expert's VR view as a visual aid (Figure 4.4d).

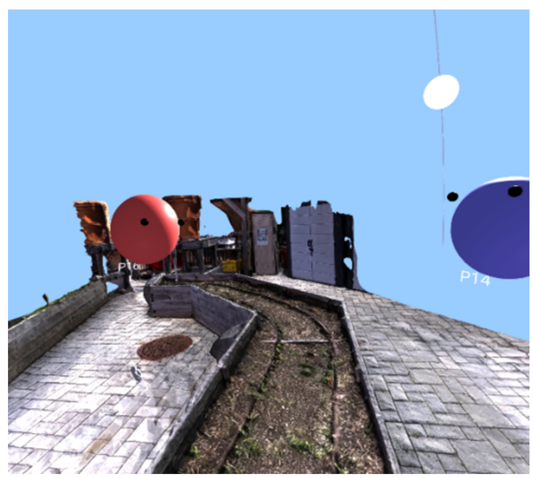
The scenarios were designed to elicit feedback on existing or possible affor-

(a) Still from video of terraced slope selected for session S7.



(b) First person view of P16 seeing rain simulated on a 3D model of the sloped terrace.

(c) Still from video of raised beds and irrigation system selected for session S7.



(d) First person view of P15 seeing avatars of P14 and P16 experiencing Scenario 2 with the virtual sun.

Figure 4.4: Examples from session S7 of areas selected by participants along with screen captures from devices used during Part 2 of the study. We can see 3D models of the garden area generated and used for Scenarios 1 (rain) and 2 (sun) along with the simple sphere with dotted eyes for user avatars.

dances for the virtual representations of areas, objects, and events in the physical garden space in XR. This includes reflecting on affordances for instructional interactions (e.g., being able to actively move a virtual sun) and social affordances for connecting (e.g., conveying stories for objects with family history). A limitation of using the web app approach was the constraint on the fidelity of the 3D models to maintain comparable loading and rendering times across the different mobile devices and the headset. Most models had between 10K to 100K triangles depending on the size or number of objects in the model. For example, empty plots or single objects needed fewer triangles. We had one outlier of a large butterfly garden model (Figure 4.3f) for session S6 with one million triangles. We restricted this model to Scenario 2 since simulating rain in Scenario 1 is more resource intensive due to the collision simulation for the raindrops and could have negatively affected participant experience with the large render time.

4.4.4 Analysis

We collected 12 hours of Zoom videoconference recordings of 1) onsite participants walking their remote partner and researcher through the physical study locations for Part 1 of the study and 2) participants using the Oculus headset or their mobile/tablet device during the XR prototype evaluation in Part 2 of our study. Prototype evaluation, in total, used 19 reconstructed 3D models of the participants' garden areas and objects (Table 4.2). An additional 6 hours of video were screen-captured from the XR environment during prototype evaluation in Part 2.

This depicted participants as avatars interacting with each other and the 3D models.

We used a qualitative approach to analyze this rich dataset from multigenerational groups having different expertise levels, goals with gardening, and perceptions of XR. We used thematic analysis (Braun and Clarke [126]) to descriptively surface the underlying subjective perspectives on the context that is important for user experience with 3D reconstructions. Our analysis was guided deductively by the study objectives, and through inductive interpretation of data. Subthemes and overarching themes related to our research questions were developed progressively using coding and memoing. The first author started by transcribing the audio from the videos for deeper familiarization with the data. During this process, the videos screen-captured during the prototype evaluation in Part 2 of the sessions provided context for participant reactions and actions in the "real" world videos. The first author then performed the initial coding of transcripts and complementary memoing to identify emerging subthemes in data. The first four sessions (S1-S4) were transcribed and coded immediately after completion. The resulting codes and subthemes were then discussed and refined by the authoring team for their relevance to our guiding themes based on our research questions. The first author and a research team member then transcribed the interviews from sessions S5-S8 and used this data to build on the refined subthemes. Although the codes around the research questions had become mostly saturated after the first four sessions, new data related to privacy when creating and sharing 3D content emerged during session S5. The researchers additionally focused on drawing out more data on this subtheme, when interviewing in sessions S6-S8. The themes that emerged from coding and memos from all eight sessions were brought to our research team for further discussion to define the final salient themes that we present in the findings section. Our first salient theme relates to the context that can be important to capture to reconstruct the physical activity space and objects for social connecting or instructional interactions in XR (RQ1). Our second theme relates to the goals of intergenerational groups and factors affecting their interactions with the reconstructed objects and areas in XR (RQ2). Our final theme is related to how our model generation approach might have affected prototype usage during the study sessions. The findings from this theme presented a limitation that can influence design considerations rather than answering a specific research question. Table 4.3 provides examples of themes, subthemes, their associated research questions, and underlying codes.

Theme	*Subtheme*	*RQ*	*Example Codes*
Context important to capture for informal settings	Context for understanding the reconstruction with real-world teaching/learning experience	RQ1A	Model missing surrounding visual references, viewing extremely fine details, ability to touch objects for teaching, describing an interconnected system, capturing life
	Context capturing relations with other people	RQ1B	Object representing family member, create familiarity with shared memory, gifting family, collaboratively built space
	Privacy when authoring and sharing 3D content	RQ1C	Interested in sharing objects you are proud of, models of private vs public areas, privacy concerns for children
Intergenerational perceptions and XR interactions	Perceptions due to values	RQ2	Unaccustomed to internet, resonates with using technology in garden, relying on on-site people for help, younger people may be more comfortable with XR
	Goals for intergenerational groups	RQ2	Goals for intergenerational groups
Effect of models on feedback	Orienting to virtual model		Couldn't identify model as real area, resolution requirement depends on expertise, landmark helped orient

Table 4.3: Examples of themes, subthemes, associated research questions (related theme), and underlying codes from data analysis.

4.5 Findings

In this section, we describe participants' thoughts on using the XR prototype to experience 3D models of familiar real objects and areas in their garden. We focus on what participants felt was the important context that these 3D models needed to capture in XR to augment instruction and connection in their informal setting. "Context" includes behaviors, interactions, and affordances that participants would like the models to support. We also describe privacy-related nuances important to participants when creating and sharing these 3D models in different settings. Finally, we describe how prototype usage may have been affected by perceptions of XR by our intergenerational groups and the models used.

4.5.1 Context Important to Users' Experiences With the 3D Reconstructed Activity Space in XR (RQ1)

As part of answering RQ1, we present our findings on contexts that cover instructional motivations (RQ1A), connecting (RQ1B) with each other, and the privacy concerns around creating and sharing such 3D content (RQ1C).

4.5.1.1 Context To Capture for Learning Experiences: Exploring Relations at Different Scales of the Garden (RQ1A)

In Figure 4.3, we give examples of 3D models from each session that were created using several types and scales of objects and areas chosen by participants from their physical garden space. Many smaller areas and objects in the garden can often be viewed as part of a larger natural or manmade system. This is especially visible in community gardens and demonstration gardens (S6 and S7) that are designed to showcase their relationship with the surrounding local environment. For example, rainwater collected in one area of a community garden might be pumped to a different area further away to supplement existing irrigation as in session S7. Master gardeners P11, P12, and P14 described how they could use models in XR to provide an overview that captured the relations between parts of the entire garden system and its interactions with the environment. Similarly, P2, P9, P11, and P14 felt 3D models could be more suited to give an overview of a garden and system rather than capturing a single object or area in isolation. It was different when teaching/learning concepts that required the remote user to explore minute details. Some participants like P2 and P5 felt video chat in the garden walkthrough allowed them to better explore these details as it *"forced you to focus on objects in a smaller field of view."* Others emphasized creating models that emphasized zoomability (P1, P12, and P18) and manipulability (P13 and P14). Although limited by technology, participants wanted to manipulate the models hands-on, especially in an intergenerational setting since kids *"they want hands-on, like we do leaf rubbings"*.

Participants also discussed additional context when representing the effect of environmental variables on the physical activity space (sun and rain in our scenarios). An example from prototype evaluation was for the models to capture how the physical counterpart might interact with sunlight. Participants mentioned that this could be based on the real object's position in the house, relative geography, and its material properties when remotely assisting a user with planning. Participants felt a difference in being able to translate their real-world experience to the virtual environment in the two different scenarios for our XR prototype. With the sunlight prototypes, some participants felt they were unable to translate their experience. This was because there were many implicit cues when thinking about sunlight distribution in a real-life space that were not captured by the experience in the prototype. An example was how the limit on the area for modeling affected P5 and P6's usage of the sunlight prototype. P5 indicated that the neighborhood around the object could have been better selected during video capture by including a larger area around the pre-created model to determine how sunlight interacted with her garden. However, experiencing how rainwater flowed across a model of their garden plot in the rain prototype felt more translatable and understandable by both partners and most other participants. P11 felt that being able to see where the water was draining off or feeding on the model in Scenario 2 was cool since *"you know, my goal is always to conserve water as much as possible."*

4.5.1.2 Context To Capture for Connecting Interactions: Emotions, Relations With People and Feelings (RQ1B)

Some objects and areas in the physical space connected our participants with their partners and with other people past and present. These could be decorative like P3's neighbor's painting for their shared gardening space (Figure 4.2c). They could also be living and "functional" like P1's tobacco patch in her husband's memory, or

P9's silver maple tree in memory of her mother. Some of them were also a product of collaborative effort. For example, Figure 4.3b shows a model that we created of a flower bed that was pre-selected by P3 and P4 for session S2. This area contains random objects like *"pieces of decorative woods"* picked up by P3 and P4's family, a gift wind catcher from P3's son, and a flamingo statue that had *"come down to live in mine"* after P3's mother passed away. Similarly, P17's house garden was full of plants (e.g., Lenten-roses) or features (e.g., winding paths) suggested by her friends and neighbors or from when *"I take walks and I see what works in other people's yards."* Some participants wanted to create an aesthetic that appealed to other people with the objects and areas in the garden. For example, P11 wanted to create a *"tropical feel"* in his garden for his mother P10 while also making his yard look presentable *"out of respect for my neighbors, you know"*.

When discussing how one might capture these objects, areas, and associated feelings, we find some participants talking about specific kinds of temporality in addition to visual detail and interactivity that was significant. Objects in the garden were also associated with a certain time at which they held more meaning. For example, in session S1, P1 described a dogwood tree that her niece P2 had planted in memory of her mother. P2 felt that she would prefer to capture the tree as a 3D model when it was in bloom and the birds were more active. She preferred a model since she could sit under it, which would not be possible with a photograph. In addition to just seeing the actual 3D model at a certain time, P1 was personally interested in being able to capture additional personalized context that would help her feel what P2 felt in some way. This could be P2 vocally describing the reasons for planting the tree. Similar examples appeared in sessions S5 and S7. P11 was interested in capturing a model of a memorial flower bed in bloom for his brother while P14 was thinking of modeling P16's maple from their front yard that had *"a picture of her (P16) hugging it"*. Some participants describe creating and sharing models that they think would just be fun. For example, P13 felt she was a more visual person and wanted to create models of flowers that she grew that could also capture their *"vivid"* color.

4.5.1.3 Context Useful for Both Learning and Connecting: Capturing "Life" and Stages of Growth (RQ1A and RQ1B)

Participants were also interested in context that captured a certain stage of growth or represented *"life"* in the garden space. This was valuable for instructing (RQ1A) and connecting (RQ1B) over their unsurprising shared appreciation of nature. For example, during the garden walkthrough, participants sometimes tried to familiarize their partners with how something might look when growing. After experiencing the prototype, P12 felt it would be great to show something growing from seed to flowering with virtual models of plants. P18 also mentions an example of being able to see the various stages of growth of a magnolia tree on a model and compare it with her own. This ties in with an interest among participants in helping others understand, like P6 for her young daughter, *"where food comes from"*.

Another way of *"capturing life"* in the garden was capturing the way that objects might interact with non-humans in the space and even demonstrate their common behaviors. P15 mentions being able to create a model of a certain bird that would allow others to better visualize its normal behavior and compare any odd pruning behavior with its physical counterpart. P14 described an annual event in his garden when *"tiny wren birds come in, they have babies"* and wanted to create and share a 3D model of some birdhouses that he made for this personally significant event. P18 talked about how they might want to create a 3D reconstruction of tiny praying mantis eggs hatching. She felt that experiencing this event as a group with a video would involve adjusting viewing angles and *"Oh, can you come a little closer?"* whereas *"as a model, you can move more around that."* An interesting use case suggested by P17 in the same scenario was to be able to create a model that was good enough to allow a remote user to "look around the garden a little bit more virtually" in real-time and suggest camera positions to their onsite partner for photography. Capturing life sometimes also involved capturing models for areas that might be unapproachable, as in the case of the bee area in session S7 (Figure 4.3g). In other cases, it might be a problem of accessibility for people with mobility constraints instead. For example, P15 felt it would be nice to create a walkable model of the forest preserves adjoining her community as a way to connect through nature. It would help *"some of the elderly shut-in... (to) give them the feeling of being outside even though they're not."*

4.5.1.4 Context When Sharing 3D Content: Privacy Preferences Related to Space and Activity (RQ1C)

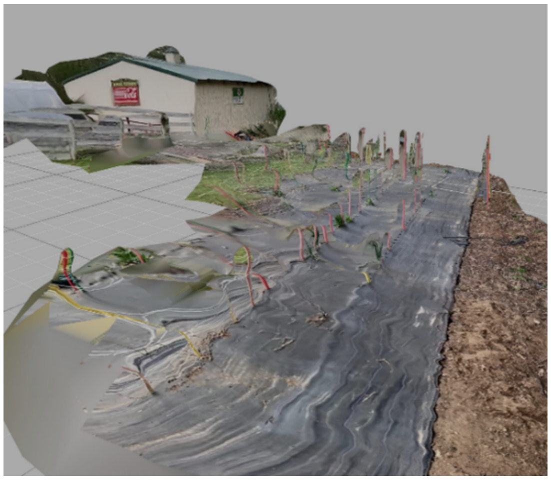
An interesting finding was related to participants' privacy concerns regarding 3D content (digital twins) they might create themselves from their physical garden spaces. These concerns appeared organically from session S5 and were pursued in the following sessions as an additional research question (RQ1C). We find that participants' openness to sharing 3D representations of real spaces, either publicly or privately, depended on a couple of factors: how they viewed their property, the motivation for sharing, and their experience with sharing photos/videos on conventional social media. For example, P11 (younger expert) felt comfortable publicly sharing the S5 session models since he viewed his garden spaces as a community resource and *"a tool to train (other people)"*. He was an enthusiastic endorser of creating personalized 3D content from his own garden for educational purposes and had already created 3D CAD-style models of his garden in the past. There was a similar shared opinion among a few other participants (older novice P10, older expert P12, younger expert P14, older expert P15) regarding public sharing for an educational purpose. For example, P12 was open to creating models of the educational spaces in master gardener demonstration gardens and sharing them publicly.

Participants were guarded to varying degrees when it came to sharing models from spaces viewed as private (e.g., inside of a house or backyard) or their own avatars. P10, like her son P11, did not have any concerns with publicly sharing such 3D content if the address of his house was anonymized. Some were more conscious and only wanted to share models of good-looking parts of their house, like what they might share on social media. For example, P13 was interested in creating and sharing models of her beautiful *"pet flowers"*. P14 felt he would not create a model of his house garden because it was *"so bad, I don't want to show it to anybody right now"*. But he also felt open to publicly or privately sharing if it *"would be a good learning tool for people who might have similar backyards or spaces."*. Some participants, like P14, felt comfortable with the public sharing of models from private spaces, more so than community spaces, after scrubbing identifying information (e.g., geolocation). P15 felt she would need to ask permission when creating models in her community gardens since *"I wouldn't feel right doing that. Because it's not my property, there are common areas and there are other households there."* These data points highlighted contrasting views that can exist regarding the extent of information that needed to be anonymized. Another example comes from session S8 where P17 was not on social media and P18 only occasionally posted pictures of her flowers for her friends on Instagram, but nothing too personal. P18 did not feel hung up about even having her house number visible. To a random viewer *"this is the number of a house in who-knows-where-ville"*. P17 on the other hand felt someone could *"match it on Google Earth"*. Another key point that P12 raised was regarding self-representation. Our XR prototype avatars felt *"really basic"* but the ability to create a lookalike avatar of oneself posed privacy concerns and required guidance when children were involved in the intergenerational setting. P15 (older adult) and P16 (teen) on the other hand felt comfortable with being recognized as themselves.

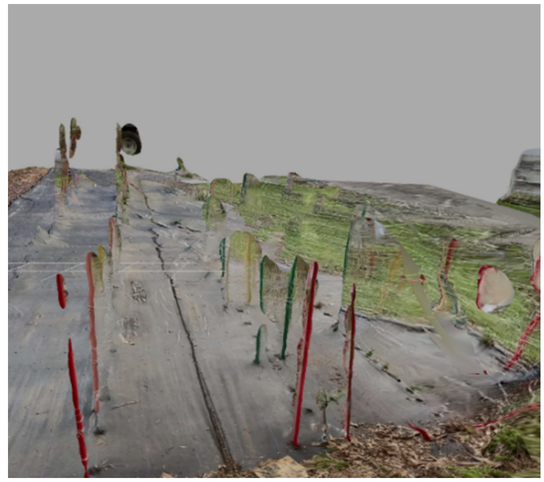
4.5.2 Interplay Between Perception of XR and Prototype Usage in Our Intergenerational Groups (RQ2)

An observation that we would like to highlight from our study procedures is the interplay between learning to work with the prototypes together and the multi-generational perceptions of XR. Most of our participants were aware of the term virtual reality but every session had at least one participant who was experiencing VR hands-on for the first time (Table 4.1). On one hand, participants had positive inputs regarding creating and using digital twins of physical spaces and objects for instruction. Not just *"for games but for actually, you know, something more purposeful and useful such as all the benefits of gardening, for example, physical emotional mental, and community, and also environmental"* (P15). Participants were interested in how such technology could be used for sharing knowledge such as passing on *"the old ways"* of tradition (P3) or educating older generations on modern sustainability techniques (P11). Others were interested in connecting by listening to family stories from their garden space (P9). However, it is also important to acknowledge that there were participants who did not see themselves using XR devices in the garden. This was despite liking the idea of capturing different objects or spaces and the related contexts as 3D models to view using XR. Some participants, such as P1 (older novice), P2 (younger expert), P3 (older expert), and P4 (experienced teen gardener) talk about how not using technology in the garden resonated with their values when they were living close by. They felt it was probably better suited for the presented use case of families or friends separated by distance when there *"was no way to have personal interaction"*. P4 talks about enjoying nature as *"a lot of this [her] generation is involved with a lot of technology, so I think getting out in the garden, you know, removes you from [technology]"*.

P3 (older expert), P7 (older expert), and P8 (older expert) felt that experiencing a remote garden using VR technology might appeal to people who were *"much more familiar with the computer"* (P7) or who *"really like technology"* (P8). While they do acknowledge that other older adults fit this category, they also mention that *"the younger generation"* (P8) would feel much more comfortable using such technology. P3 even mentions that young kids like her granddaughter P4 might find it more interesting *"as you can see, P4 was just fascinated with what she was doing while she had [the headset]"*. These specific older adult participants however seemed willing to try such a prototype because it was an intergenerational setting with someone they knew. We find that it may have helped participants to have assistance from their older or younger study partner or to just bounce ideas off them when troubleshooting issues with the device or prototype (e.g., orienting to the model of the garden based on familiarity). Even P10 (older novice) who was academic and familiar with new technologies mentioned being excited to try the technology and having P11 walk her through using the Oculus Quest headset before the session. We have previously noted the values of our participants related to technology in the garden and how XR might be viewed as unnecessary by some, regardless of age or tech familiarity. The motivation to share knowledge and the dynamic of helping each other use the prototype may have enabled us to obtain more positive feedback than expected despite these perceptions of XR for a garden.



(a) Viewpoint for the model of P3's farm plot which was relatively recognizable with the large barn landmark. Objects like the vertical stakes look distorted.



(b) Alternate viewpoint of the model showing issues with directional fidelity. Some of the vertical stakes look better here.

Figure 4.5: One of the models for session S2 which participants described as difficult to recognize and unnatural like a *"Martian landscape"*. Corresponding photograph of the physical area in Figure 4.2b.

4.5.3 Effect of Model Quality on Prototype Feedback as a Limitation

The video collection method to generate models using photogrammetry might have been a factor that affected prototype usage and feedback. As mentioned earlier in section 4.4.3, the amount of data used in the photogrammetry process and the resulting fidelity of the models presented to our participants was limited by the web app approach for our prototype. For this reason, some models initially felt unfamiliar to participants. They required time to orient to major landmarks and view the model as natural. P3 felt the model of her farm plot resembled more of a *"Martian landscape"* and the barnyard acted as a unique landmark (Figure 4.5a) to help their group orient themselves. A functional use of the models, for example, when simulating rain in Scenario 2 also helped participants overlook the model quality issues. Some, like P12 and P13, in session S6 were impressed with the quality of the models we were able to create for them, even after initially feeling lost. P12 mentions that people might have different opinions about how *"vivid or lifelike"* they might want the model they capture to be for instructional purposes, depending on their level of expertise. The fidelity of the models also was directional, with the XR users seeing better visual quality with certain viewing angles and distortion of the models from other angles (Figure 4.5b). This might have been due to the technique suggested to participants to collect videos for model creation by moving around an area or object which resulted in more photos from angles where the users focused on objects longer. The viewing angles explored in the videos might also have been influenced by the movement area available to the participants since gardens are often full of objects that restrict mobility outside of a built path (e.g., bushes, rocks, muddy terrain). While the videos for photogrammetry were captured from a distance that allowed the entire area or object to be visible, there was a variation in this distance depending on the target's size. This might have caused variation in capturing the neighborhood of the target object or area which was a key factor in realistically visualizing environmental effects, as mentioned earlier in Section 4.5.1.1 by P5. Overall, the low-fidelity constraints and visual artifacts in the 3D models might have affected their perception of the state of XR and how one might interact with these models.

4.6 Discussion

Our findings describe context from informal settings that participants felt was important to the user experience when interacting with virtual reconstructions of real areas and objects in XR. In this section, we discuss what these findings might mean for perspectives on creating and sharing 3D models of meaningful areas and objects. We focus on how they fit into the space of 3D contextual capture for instruction and connection.

4.6.1 Capturing Context for Meaningful Reconstructions of Objects and Spaces for Informal XR Learning

First, we discuss possible limitations for XR user experience and approaches to capturing context through 3D models when instruction involves objects at different scales. We also note potential challenges with translating real-world experience to reconstructions of objects and spaces.

4.6.1.1 Supporting Meaningful Reflection During Remote Instruction (RQ1A)

Our findings described how the scale of the selected meaningful objects and spaces allowed for discussion related to different objectives. Conventional video seemed more suitable when remote learning involved focusing on minute details, while XR seemed more suitable for visualizing relatively larger systems and their relationship with the environment. Past work around multi-scale interactions in XR, has also noted lower visual quality as a tradeoff for exploration with 3D models over video in other remote-guidance settings [184,185]. So, while video might be sufficient to capture context at smaller scales, designers might benefit from leaning more into enabling the user to change perspective at different scales with XR. This can augment different kinds of reflection or instruction in remote collaboration systems (e.g., first-person and third-person [124, 186, 187], giant-miniature [184], using 360-video [146, 150, 188], or 3D reconstruction [91]).

User experience with interactions at these different scales and perspectives could benefit from exploring different approaches to reconstruction. This could help identify other types of contexts to capture for meaningful reconstruction which could augment reflective and shared memory practices among the users about the activity and the physical space and objects. Our findings noted that the approach to capturing the models and reconstruction artifacts posed some limitations. A physical constraint of the data collection method we used for reconstruction was that participants had to select objects and spaces that were easier to walk around. Consequently, objects needed to have features that were visible from the walked path. The models did allow the participants to reflect on certain types of contexts to capture at this scale like socially shareable features, and interaction with the environment (e.g., rain or animals). A hands-on physical approach to learning, as in gardening, might be better served through a technique like in-hand object reconstruction [189] from a first-person video. This might be useful for the collaborative exploration of minute details by naturally selecting and pointing at the important context for hand-scale objects with hand interactions. The interactions in this approach could reveal affordances (e.g., tactile) that onsite users would want the model to have as context for the remote user. Again, a conventional video that is zoomed-in might be preferred for minute details and could be a benchmark when comparing more interactive ways of reconstructing such detailed objects for remote collaboration.

We have also seen participants discussing the advantages of seeing the relations between different objects and areas as part of a garden system and the surrounding environmental context. Enabling a learner to visualize a particular system component within a broader landscape can augment how they reflect on its role. YardMap is one such example project, where crowdsourced labeling of 2D neighborhood maps allows for reflection on land use and wildlife behaviors [190]. 3D representations in XR can be a powerful perspective-taking medium to reflect on the environmental effects of human activity [133]. Researchers could explore how individual, or group input could help reflect on and identify context for reconstruction that can support reflection for people of all expertise levels. For example, by deciding on a meaningfully sized neighborhood to gauge the impact of environmental variables like rain. Designing reconstruction for this purpose could involve allowing users to capture context surrounding a specific object or viewpoint [191], for example, from a bird's-eye drone or third-person perspective [192], or 360 imagery.

4.6.1.2 More Implicit Context Required To Understand 3D Models With Real-World Experience (RQ1A and RQ1B)

"If a picture is worth a thousand words, one could argue that a model is worth a thousand pictures, or a million words" [161]. However, this depends on whether there is contextualizing metadata to help with assessing and reusing the model. Past work has explored adding different contextual information (e.g., user annotations, sensor data, audio) to conventional 2D media to enable different interactions for sensemaking and creative expression [193–195]. Our findings show examples of such context that participants felt were important when providing instruction or for social connection using 3D reconstructions. Providing a shared visual context explorable in an embodied manner is an advantage of XR systems for remote collaboration [103, 105]. However, our findings (Section 4.5.1.1) show that sometimes scenarios that are assumed to be intuitive for simulation with a reconstructed model aren't necessarily so. There is implicit or intangible context [196] from real-world experience that is lost even if we have a high-fidelity reconstruction of a 3D environment. We find this in the case of sunlight visualization over time using the reconstructions. We had selected it as a promising use case for visualizing time in XR from Maddali et. al's [9] study on use cases for expert-novice guidance with 360 image environments. However, the feedback on this scenario shows that it required much more implicit context, for example, a meaningfully sized neighborhood of influence around the object.

Our findings also talk about themes such as capturing *"life"* and growth that might be expected from a nature setting. These were operationalized for reconstruction by participants as being able to show visuals at various stages in time, or as behaviors expected from objects or non-human beings that inhabit the space. The idea was to have a reference to compare with a physical counterpart and evaluate, for example, growth or normal behavior. Being able to virtually represent animals and their presence (e.g., ambient sound of the environment) or behavior (e.g., swarming) authentically, especially from an environment inaccessible to people, can augment connecting interactions in environmental education [9,197]. However, reconstruction of animals is an especially challenging task and doesn't lend itself well to live settings, since they aren't static and rigid objects [198]. This limits how personalizable such reconstructions can be for informal connecting interactions compared to traditional videos/images. As a design consideration, rather than the ability to create high-fidelity models, searchability and sharing of models might be more important depending on whether the objective of the users is learning or connecting. Digital sharing approaches could just make existing libraries of professionally constructed virtual 3D models easily accessible on the interface for social interaction (e.g., AR animals in Google searches [199]) or even temporally-filterable searches (e.g., for a young versus grown flowering plant).

4.6.2 Reflecting on Privacy Nuances When Creating or Sharing 3D Models for XR (RQ1C)

The growing ubiquity of XR for casual use adds yet another set of devices for which users must reflect on personal privacy implications. XR devices pose a unique challenge since they inherently rely on mapping their surrounding space to connect the physical surroundings with their virtual environments and enable spatial interactions [200]. Industry initiatives (e.g., Niantic's Planet-Scale AR Alliance [201]) envision a future where "world scraping" [202] through XR devices will allow for "live maps" [203] of reconstructed 3D spaces to the level of specific object locations. This kind of mapping can enable useful applications, for example, accessible navigation [204]. However, they also further blur the idea of what XR users consider as private space or objects and what context is private specifically for reconstructions in XR. Our findings describe a few perspectives on privacy when creating or sharing 3D reconstructions as a casual XR user. The process of capturing and sharing models could be influenced by participants' thoughts on what was a private or public space and what context they might want to share. Wang et al. [162] describe this context for the casual sharing of dance movements as 3D reconstructed moments. They also acknowledge that privacy considerations might change within different contexts as informed by previous work by Li et. al on photo-sharing [205]. Our findings confirm this assumption and extend past ethnographic findings on sociality in such informal spaces. We have provided an example of how educational motivations were more correlated with openness to public sharing of 3D models from personal garden spaces. Users should be encouraged, through design, to define privacy for spaces, objects, and any important related context. An approach from past work is to help casual users reflect and identify context whose importance to privacy might be overlooked during reconstruction [206, 207]. Designing for visibility of motivations and preferences related to an object considered private could be another approach to inform outsiders [28] reconstructing or sharing a model of the same object. For example, allowing the user to select a space around an object that can provide enough context to visualize interaction with the sun but hides a house number or a neighbor's plot. Further, in an intergenerational setting, designers must balance protecting the privacy of more vulnerable members of the activity space with capturing meaningful context when creating and sharing models [208]. Our findings provide an example of the possible risk of self-representation using a reconstructed avatar that younger users might not recognize. Future work could specifically try to understand how these vulnerable members might approach the context capture process to better tailor it for their privacy preferences.

4.6.3 Capturing Context From the Garden for Social Connection and Intergenerational XR

Our findings provide an understanding of the context that can capture social relations and emotional context. We discuss implications for authoring and sharing 3D content that can represent shared memories. We also discuss settings outside of gardens where exploring meaningful reconstruction of spaces and objects could augment intergenerational learning and social interactions.

4.6.3.1 Value of Reconstruction in Preserving Shared Memories (RQ1B)

Personal environments, like the home, are often likened to an "autotopography", a spatial and physical representation of their resident's individual story [209, 210] as we've seen in our findings. Shewbridge et. al [211] in a cultural probe study discusses how, for a future where 3D printers are integrated into a home environment, participants often selected unique artifacts in their house with sentimental value as something they would want to scan and create accurate or similar physical replicas. We also find ideas in literature on using immersive media (e.g., 360 panoramas) to preserve the memory and feelings associated with notable individuals' private spaces by reconstructing how their belongings were arranged [191]. Only recently, there has also been commercial interest in making it easier for everyday users to create 3D or 4D reconstructions of personal environments or shared moments using photos and videos [212, 213].

Community and hobby spaces like gardens can be viewed by researchers as a "sociotopography" in addition to an autotopography. Here, objects and spaces are ascribed a shared meaning by groups (e.g., family or practitioners) [9]. Our findings present examples of these and some shared motivations for why participants might want to have virtual representations they would like to use in remote interactions. We identify a few related design considerations from Section 4.5.1.2, where participants wanted to reconstruct an object or space representing a generational connection. First, it was important to identify the context that represents the object at a particular time (e.g., the time of bloom). Second, there can be some embodied interactions with the virtual representations that can be meaningful to the user experience (e.g. hugging it). For example, sitting under a virtual replica of a tree can capture context that represents nostalgia using XR. Finally, there might be a need to contextualize the sensory reconstruction with other social data, like a narrative [209] from the person who finds it meaningful. This can be helpful for a viewer to make sense of the same context.

There is a growing interest among HCI researchers in understanding the role of digital technology in shared memory practices through creating and sharing artifacts. We encourage researchers to think about whether the virtual reconstructions can augment preserving family memories and heritage on a more personal level as part of casual XR, in the same way that reconstructions of museum artifacts preserve cultural heritage [191]. A question to consider is how exactly these reconstructions would be perceived in terms of value for reminiscence in intergenerational settings or as mementos that are useful for connecting interactions. There is much work on comparing physical with digital mementos, where the physical mementos arguably require more narrative to explain their significance, and digital mementos are portrayed as less emotionally expressive [214]. Would virtual reconstructions in XR be valued closer to conventional digital artifacts, like 2D photos or videos since they inherently have no physicality without being 3D printed or viewed through an XR device? Alternatively, virtual reconstructions could also be seen as closer to physical artifacts since our participants felt they can be experienced in an embodied manner in XR. This can have interesting implications for how memories are captured, shared, and used in connecting interactions in the future.

4.6.3.2 Other Physical Spaces for Casual XR as a Medium for Intergenerational Activities (RQ2)

If we imagine the future of remote social interaction to be tied in some way to XR, we will ideally want XR to be welcoming and accessible [73] to users of different ages, abilities, and backgrounds while respecting their motivations, values for activities chosen as use cases, and privacy considerations. Our findings in section 4.5.2 presented some perceptions of whether intergenerational groups would use XR for such remote collaboration in the garden. We see that these perceptions were not necessarily related to age and might have been more correlated with self-described tech familiarity. The values that arose from gardens being a nature experience removed from technology, as described in past literature [9, 27, 35], also influenced them. Most of their positive experiences around interacting with the 3D reconstructions were centered around sharing knowledge between generations, encouraging reflection (e.g., on environmental effects), and representing shared memories. These are not exclusive to the garden space.

Past work has studied learning spaces in other activities notably characterized by intergenerational participation. This includes more human-made-artifact-oriented activity spaces such as makerspaces [215] where virtual representations of objects using technology have become integrated into the process of ideation and making [216, 217]. Artisanal activities entrenched in tradition (e.g., pottery, papermaking) have also seen interest from HCI researchers as settings for capturing context representing tacit knowledge and augmenting learning using XR [218]. The applicability of our findings on experiences with 3D reconstructions of real spaces and objects in these activities is a question that might interest designers. While hobbyist values might be comparable across activities on a high level, preferences for technology might differ [27]. A factor for this could be that technology might blend in better with, for example, a makerspace environment compared to a natural space, as we have seen in our findings. Other relevant, more every day, activity spaces might be found inside the home (e.g. kitchens). Panicker et. al [219] encourage supporting and creating shared experiences around eating and meal preparation by, for example, facilitating cooking together across distances. The XR industry is in the process of finding more of these meaningful and practical everyday use cases for casual users. At the risk of sounding techno-solutionist, we would like to encourage more support for exploring applications that can meaningfully augment remote group experiences for an intergenerational audience. There is clearly an interest in the potential applications for remote XR to go beyond entertainment and work productivity. But the perception of XR being an accessible and general-purpose remote collaboration technology is not there yet.

RQ	*Findings*	*Implications*
RQ1A	- XR better for learning about larger systems in garden compared to video for minute features. - Implicit context not easy to understand from 3D models. - Interest in capturing "life"-like behavior and comparing with real.	- Capture context for perspective taking and reflection using reconstruction at different scales. - Allow users to define a meaningful neighborhood around object to better capture implicit context
RQ1B	- Time or state of object can be meaningful (e.g., in bloom). - Embodied experience with models is meaningful (e.g., sit under) - Narrative context helpful to understand relation with model.	- Ambiguity in perception of value of 3D representations vs 2D media - Context, like embodied interaction, is a plus for XR
RQ1C	- Educational motivations positively correlate with sharing 3D models of personal spaces. - Contrasting views on extent of context (e.g., location) to anonymize.	- Design to encourage user to reflect and define privacy for space and meaningful context. - Designing for visibility of motivations and preferences related to objects to outsiders.
RQ2	- Contrasting views on using 3D models vs onsite in nature. - Perception of appealing to younger or more tech-familiar users. - Positive intergenerational dynamic when exploring XR ideas using the prototype.	- Learning and remote family use cases still meaningful. - Contrasting experiences from a tech-integrated activity space (e.g., indoor) suggested.

Table 4.4: Salient Findings and Implications

4.7 Conclusion

Through an XR prototype evaluation study with eight intergenerational groups of 18 closely related gardeners, we provide an understanding of the context required when creating meaningful virtual reconstructions of physical spaces and objects to enable instructional and connecting interactions in informal settings for XR users. Participants linked health, creative expression, and intergenerational knowledge-sharing motivations with objects and areas in their gardens holding shared meaning. We find that these motivations translated to reconstruction requiring context that captured relations between areas and objects at different scales, the emotional context for relations with other people, and privacy considerations when creating or sharing the 3D models. We discuss implications for user involvement to create reconstructions that better translate real-world experience, encourage reflection, incorporate privacy considerations, and preserve shared experiences with XR as a medium for informal intergenerational activities.

4.8 Acknowledgements

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Chapter 5: Conclusion and Future Work

The objective of my dissertation was to understand the role that technology might play in achieving skilled hobby practitioners' desired social, personal, and community objectives related to skill sharing in remote expert-novice groups. To achieve this, I focused on the popular and multigenerational hobby of gardening as a setting to study considerations for such remote skill sharing technologies.

5.1 Key Takeaways and Contributions from Study 1

I started with participant observation methodology in my first study to explore the experiences of gardeners and understand how they configure their relationships with other practitioners in the activity space. I answered the following initial research questions:

- How do practitioners engage socially as they garden?
- What kinds of social interactions facilitate skill sharing in the garden?
- What are some key opportunities for computer-supported collaborative work in this space?

Some of the key takeaways for HCI researchers and designers from Study 1 are noted below.

5.1.1 Teaching and Learning Embodied Skills in the Garden

I found that learning in the garden could take place through direct social interaction and indirectly through the observation of traces left by other gardeners in the activity space. A design opportunity in this direction is to preserve and share traces of skilled gardeners' routine actions that could support this kind of observation-based learning.

5.1.2 Designing for Varying Social Preferences

Gardeners configured their activity space to be more open or intimate using living and non-living objects to reflect their sociality preferences. These preferences varied with changing moods, tasks at hand, and the constraints and possibilities of a particular gardening space. Further research might consider how sociality varies across different activities or types of interactions and how this relates to activities seen as social or purposeful, for learning or for the community, and by different kinds of practitioners.

5.1.3 Negotiating Inclusion and Ownership

When designing for public digitally-mediated interaction in the garden space, it is necessary to think about how one might encourage the community to respect boundaries established by the gardeners. Some of the possible design opportunities in this direction include exploring ways for gardeners to highlight and share the meaning that different objects or plants hold for them and their community.

5.1.4 Accessibility and Connection

Ensuring access for people with disabilities and mobility constraints was a priority, especially for community garden spaces. A research direction that I identified for subsequent studies was to investigate technology's role in supporting accessible gardening, virtually visiting garden spaces, and providing opportunities for experts who can no longer garden to remotely share valuable skills with novices.

5.2 Key Takeaways and Contributions from Study 2

Study 1 highlighted the potential for immersive technologies such as XR when teaching and learning embodied gardening skills in expert-novice groups. I investigated this in Study 2 by exploring the feasibility of XR in the garden space and design consideration for remote skill sharing in the garden using XR.

I answered the following research questions through semi-structured interviews based on 27 practitioners' interactions, as expert-novice groups, with low-fidelity prototypes and XR design probes.:

- What are practitioners' perceptions of using XR for skill sharing?
- What interactions could be supported in XR for novice versus expert gardeners?

- To what degree might users benefit from XR technology for collaboration in the garden?

Overall, Study 2 highlighted the potential of XR for remote skill sharing in informal hobby settings while identifying challenges and opportunities for practitioners when conveying information and connecting with others in an XR representation of a remote garden. Some key takeaways from Study 2 when designing for remote-skill sharing and XR in hobby spaces are noted below.

5.2.1 Merits and Limitations of XR for Skill Sharing in Gardening

- Practitioners viewed remote skill sharing positively when in-person gardening was not feasible. XR provided different challenges and opportunities for experts and novices when supporting key interactions like instruction, observation, discussion, and connection.

- The ability to observe by independently orienting oneself to explore and annotate the activity space could be viewed as a merit for XR by a remote expert or novice. Instructional, collaborative, observational, and discussion activities that involve the passage of time, reflecting on the past, or envisioning the future are particularly suited for XR applications.

- One of the challenges affecting the experts stemmed from the limitations on sensory engagement with the remote environment using XR. Experts tried to compensate, for example, by using visual cues or with the help of the remote/local user instead of measuring by feeling in an embodied manner as they would on-site.

5.2.2 Augmenting Building Common Ground Through Connecting Interactions in XR for Hobby Settings

- Personal and social connecting dimensions must be central in informing system design when supporting hobby activities. I identified connecting interactions between our participants that seem to be important when building communal and personal common ground. XR has the potential to augment remote connecting interactions, making the learning experience more intimate compared to conventional video or audio methods.

- Practitioners should have ways to meaningfully express communal or personal significance when representing spaces and objects in XR. Leveraging familiarity can play a key role in representing spaces and objects for connecting interactions in XR. Practitioners were more comfortable sharing stories in the context (e.g., community history, local environment) of their own garden.

- Practitioner perspectives on the need for realism in connecting interactions varied depending on the task and actors involved. In some cases, participants preferred realistic representations of objects, while in others, they were more focused on the action itself.

5.3 Key Takeaways and Contributions From Study 3

Study 2 reveals affective connecting interactions to be an important design dimension for skill sharing in a hobby setting. I also realized that a deeper understanding of the social and instructional context from the practitioner's activity space was needed to understand how XR could enable these connecting interactions. Studies 1 and 2 pointed towards meaning attached to physical and virtual hobby activity spaces and objects and how practitioners connected through them. In Study 3, I further investigate the context important to practitioners when creating virtual representations of meaningful spaces and objects for XR skill sharing systems.

I answered the following research questions through user studies with 8 intergenerational groups of 18 gardeners using a remote XR prototype that allowed them to experience reconstructions of meaningful spaces:

- What is the important social and sensory context that can influence informal XR users' remote experiences with virtual representations of real activity spaces and objects?
  - What context is important to users for learning experiences with reconstructed spaces and objects?
  - What context is important for connecting interactions with reconstructed meaningful spaces and objects?
  - What context is important to users when sharing reconstructed meaningful spaces and objects?

- What are some design considerations for XR to support the values and goals of an informal inter-generational group interacting with the virtual representations?

Overall, Study 3 contributes to the understanding of the social and sensory context that can impact the experiences of XR users with reconstructions of spaces that are meaningful to them. This includes being critical of privacy implications, and the potential for intergenerational engagement and learning through 3D reconstructions. The key takeaways and contributions from this study are noted below.

5.3.1 Ideas on Supporting Meaningful Reflection During Remote Instruction

I found that video was more suitable for focusing on minute details, while XR was better for visualizing larger systems and their relationship with the environment. HCI Researchers could explore different approaches to reconstruction, that take different scales and perspectives into account to improve the user experience for remote learning through XR systems.

5.3.2 More Implicit Context Required To Understand 3D Models With Real-World Experience

- My findings highlighted the importance of implicit contextualizing metadata when using 3D models. I found that some scenarios assumed to be intuitive for simulation with reconstructed models were not necessarily so. This is because of implicit or intangible context from real-world experience that is lost even with high-fidelity reconstructions.

- The gardeners suggested considering themes like capturing *"life"* and growth in a nature setting, including using visuals at various stages in time or representing expected behaviors from objects or non-human beings inhabiting the space. XR was seen as a value-add over conventional video when learning about big-picture relations related to distributed systems in larger garden spaces and between their private space and local environment.

5.3.3 Perspectives on Privacy When Creating or Sharing 3D Reconstructions

- I found that privacy considerations may change depending on the context and motivation, such as educational purposes. XR users should be encouraged, through design, to define privacy for spaces, objects, and related contexts. Designing for the visibility of motivations and preferences is important in this case.

- Designers should consider approaches that allow users to select the level of privacy they want for their reconstructed models. For example, users could choose to provide enough context to visualize interactions with the sun while hiding house numbers or neighbors' plots. It is also important to balance privacy protection for vulnerable members of the activity space, such as younger users, with capturing meaningful context when creating and sharing models.

5.3.4 Value of Reconstruction in Preserving Shared Memories

My findings emphasized the potential of XR in preserving family memories and heritage on a personal level, similar to how reconstructions of museum artifacts preserve cultural heritage. It is important to consider how virtual reconstructions would be perceived in terms of value for reminiscence and as mementos for connecting interactions.

5.4 Reflections on the Research I Have Pursued as Part of This Dissertation Work

Gardening provided a challenging exploratory space to consider the role of immersive technologies to convey embodied experiences. I approached my dissertation research through a process of immersion in the activity by participating myself and situating the majority of my study procedures in the activity space. This helped me, through my own experiences, better detail the rich personal, communal, and environmental context that often characterizes the activity space and objects that practitioners interact with as part of learning and connecting. I was also in a better position to highlight tensions between introducing a technological medium like XR to convey this context remotely even when there can be scenarios where enabling remote experiences could have perceived value.

HCI work in the space of designing XR interfaces or systems predominantly uses quantitative or mixed-methods approaches with usability studies. So this dissertation can be considered unorthodox not just in considering gardens as an activity setting but also in the analytical approach. My original plan was to transition into a more mixed methods approach, for example, that used system usability scale questionnaires, to evaluate collaboration and task experience with my prototypes. This would have been natural to do for Studies 2 and 3 after I built a theory of how people view their physical space and objects in Study 1. However, from my personal knowledge of existing literature and the state of the industry, I felt that designing XR systems often deprioritize what the user sees and expects from the technology. Continuing with a qualitative approach in Studies 2 and 3 has been a rewarding process. I feel it helped me lead a perspective-based discussion and allowed my participants to discuss, at length, the pros and cons of my research, for example, possible concerns with applicability to their own lives or for technology that their children or grandchildren might use in the future. Keeping these tensions in mind, there was still optimism around remote XR that was constantly shared by my participants throughout this dissertation work. This was largely in part due to being able to the promise of being able to someday share stories, skills, and the "old ways" with loved ones using photo-realistic avatars and reconstructions of meaningful objects that can be experienced as if they were physically present. The work in this dissertation should therefore be seen as a proposition as well as a critique of the kinds of activities that XR can meaningfully augment and how it could do so even after XR devices become capable of realizing these idealistic experiences.

XR and its encompassed technologies of Augmented/Virtual/Mixed/Projected Reality have long been one of the future paradigms for user interfaces. Much has been said in academic and non-academic work about its potential to revolutionize remote collaboration and learning. This is not the first wave of XR devices [220]. But, this is certainly a wave that has seen a relatively widespread consumer adoption of devices in the form of HMDs, XR-capable smartphones, and tablets. So some of XR's potential is in the nascent stages of being realized for everyday consumers. There are still many limitations on how usable, accessible, and affordable XR is to users of different ages, abilities, and backgrounds. I have already alluded to this point in the discussion for Study 3 (Chapter 4). This was also one of the reasons why, in Study 3, I decided to develop prototypes that could be used by any user with a browser and mobile device capable of displaying XR experiences. It allowed me to broaden the range of participants whose feedback I could remotely get when they didn't necessarily have access to an XR HMD to experience my prototypes. The browser-based experiences acted as a familiar-seeming gateway to XR for participants who were unfamiliar with it. They also gave me important feedback on whether some practitioners of activities with a focus on in-person experiences would prefer or dislike certain form factors of XR. It needs to be mentioned that the process of conducting an ethnography-based study and going through various low-fidelity prototypes before finally introducing a full-fledged high-fidelity XR prototype to participants might seem drawn out to many researchers. However, one of the reasons for this was to account for the sensitivity of gardeners to the introduction of technology in a garden space. Many participants started with an anti-tech perspective. So slowly introducing them to the idea of XR through these gateway prototypes helped them exercise their creativity and imagine possibilities for the technology before experiencing the ground reality of what was possible with currently available commercial technology. Other activities, where the culture is more accepting of technology, may not need such a delay between introducing concepts and a full-fledged XR prototype to evaluate attitudes.

A secondary analysis of the interview data from the first four sessions of Study 3 was performed to reveal asymmetries in experiences with accessibility for intergenerational users of my XR prototype. This was led by my mentee Vibhav Nanda with guiding feedback from me and my advisor Dr. Amanda Lazar for the analysis and presentation. The findings of this secondary analysis have been published at ACM SIGACCESS Conference on Computers and Accessibility, (ASSETS 2022) [11]. Although this related work has not been used for this dissertation work, it can serve as supplementary material to highlight the potential accessibility concerns when using social XR for intergenerational activities.

Due to the outdoor nature of gardening, there were also many engineering challenges for the XR prototypes and conducting the studies. I had to limit the initial sessions of Study 2 to shaded areas since the intense sunlight was negatively affecting the VR headset's position-tracking ability. Using WebXR in Study 3 with tablets slightly helped with the outdoor operation. WiFi connectivity in the outdoors was another major issue. The community gardens I visited had rare or non-existent access to a WiFi connection and spotty mobile 4G access. This access to the internet in the outdoors will likely improve as the world transitions towards 5G and 6G.

5.5 Future Work

I expect that the findings of my dissertation will impact how technology, specifically based on XR, will be designed and evaluated for the objective of instruction and connection in physically skilled hobby activities. One of the directions I see for future work that builds on my dissertation research includes understanding the role of XR as a medium for the preservation of generational family skills and traditional artisan knowledge. This includes exploring XR design considerations for other physically skilled hobbies such as woodworking, ceramics, etc. It would be interesting to explore practitioners' perspectives and the implicit or explicit context that XR would need to capture for learning processes in these more tool-heavy skilled activities. There are also related questions from Studies 2 and 3 to explore in future work about the perceived value of physical objects versus virtual reconstructions versus conventional 2D media as mementos for connecting interactions.

Another research direction from my research is investigating privacy considerations of space for XR for informal use cases. I have already talked about the challenge that XR poses when thinking about private and public spaces since it is a technology that inherently relies on, for example, seeing what the user sees. In a sense, it captures the embodied sensory experience of the user more intrusively than other conventional technologies for communication. There are privacy concerns that need to be prioritized by XR designers as it becomes easier for more users to reconstruct the objects and spaces they would like to bring into an XR environment. Future work could focus on providing a deeper understanding of the context for reconstruction and tensions between the privacy considerations of different users and the need to create meaningful reconstructions when connecting via XR. My findings from Study 3 revealed some privacy concerns that appear related to the approach to reconstruction. However, the limitation of my dissertation work was the researcher (me) producing the reconstruction even if the participants themselves might have chosen and provided the data. In the very short time between completing the final study of my dissertation and defending it, there have been multiple amazingly accurate 3D reconstruction tools that have been released publicly (e.g., NVIDIA's instant NeRF [221], Apple's Object Capture API [222]). Future research investigating XR experiences with reconstructed spaces can produce more user-centered insights on privacy from the participants reconstructing using these now mobile-ready tools on their own devices. It could directly benefit, for example, an understanding of how to design for applications involving relatively less privacy-literate users or a younger generation growing up with increasing exposure to these technologies.

Appendix A: Storyboards used in Phase 1

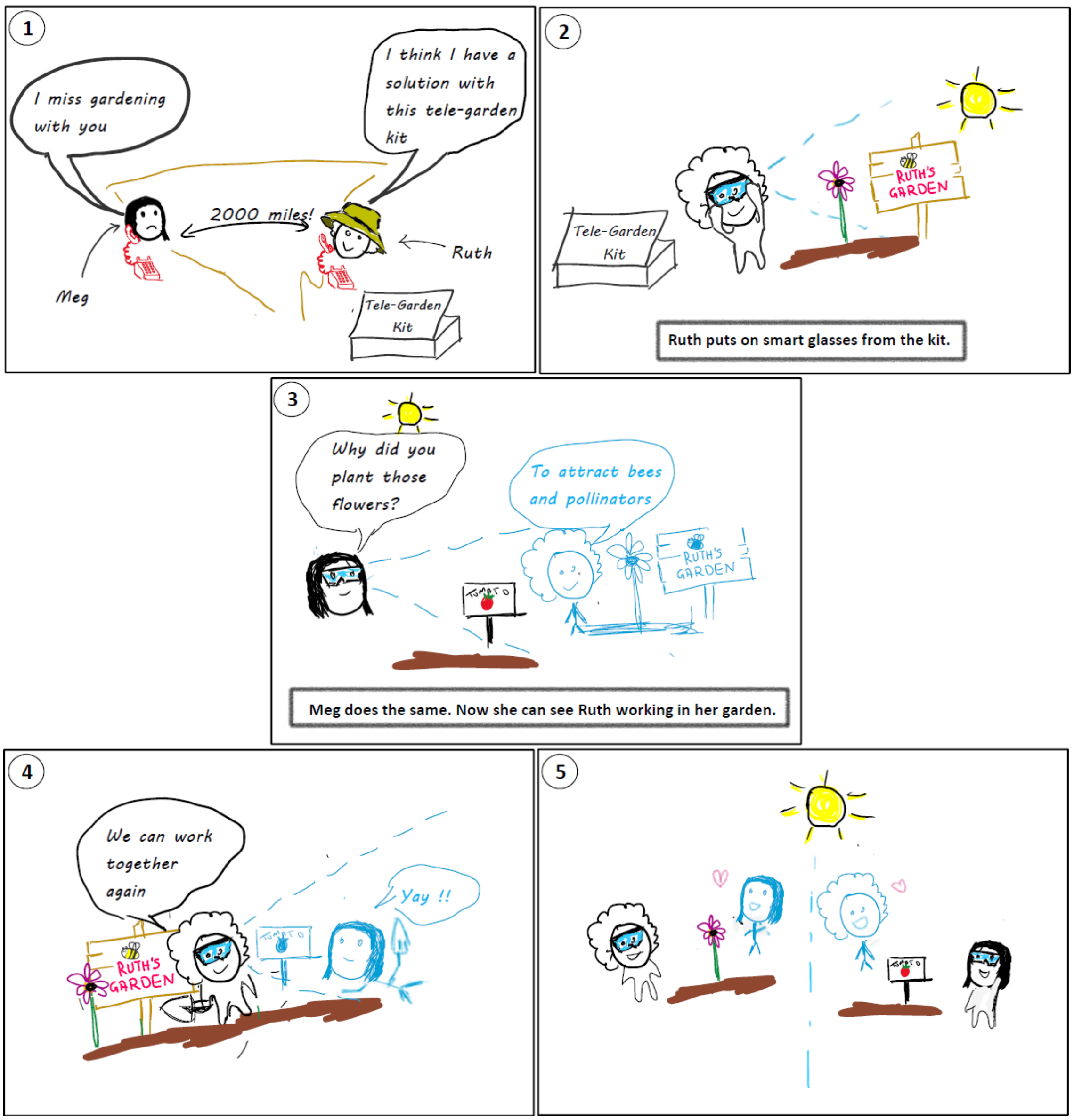

Figure A.1: Panels from the Collaborative Gardening storyboard.

Figure A.2: Panels from the Expert Mentor storyboard.

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