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

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As extended reality (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 have been well-studied in HCI and may similarly benefit from remote skill-sharing. However, little is known about how XR technologies might support expert-novice collaboration for skilled hobby activities. This paper examines the potential and limitations of XR to connect experts and novices for one such activity: gardening. Through two studies involving 27 expert and novice gardeners, we designed prototypes to understand 1) practitioner perceptions of XR and remote skill-sharing in the garden and 2) what kinds of interactions can be supported in XR for expert-novice groups. We discuss design opportunities and challenges for XR systems in supporting informal connecting interactions and meaningful sensory interactions with a remote environment during skill-sharing.

CCS Concepts: • **Human-centered computing → Human computer inter-action (HCI)**; **Collaborative and social computing**;

KEYWORDS: Extended reality, Skilled hobbies, Skill-sharing, Gardening

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1 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 [70]. 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 [37] 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 understanding 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 [5,68], surgery[18,46,69]). Often, these systems are designed to improve learning outcomes over traditional video for expert-novice team scenarios, for example, facilitating remote experts in guiding novices in equipment repair or maintenance processes [19]. Prior work has presented remote expert XR

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systems for teaching other physical activities such as musical instruments[64] or movement training [3,24].

As inquiry in technology research and design expands outside of the professional workplace [9] into skilled hobbies [50,61,45,51], there is an opportunity to understand whether XR can similarly succeed in supporting remote collaboration in the 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[36]. Further, hobbyist learning can also focus more so on learning a way of a life related the activity as a form of serious leisure[55] rather than improving one's skill with an economic incentive in mind[12]. Other differences which may affect user needs and design of XR guidance include social interaction, community history, strictness of adherence to ethical standards, and if adequacy of training is evaluated in an institutional manner [56].

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[54,60], the importance of relaying context for learning physical tasks[59], and perspectives on nurturing sensing capabilities and mentor-apprentice relations through technology [31,57].

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 [6,25,35]. 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 [48], as apprentices [25], and with family and friends [34,66]. However, with deskilling in food production due to industrialization and mechanization [14], there can be a lack of local access to gardening knowledge which may challenge the implementation of gardening education [15]. Past research has called for further study on how technology might support education around food production [25]. Given that conventional video communication can be inadequate when supporting educational activities where practitioners physically manipulate physical objects [33], and XR systems have been well studied in research on remote expert instruction for physical tasks with established sequences of actions (e.g. equipment assembly [39], surgical procedures [4]), there is an opportunity to understand whether XR could be a suitable medium to also deliver remote learning experiences to distributed gardeners in a hobbyist setting and when XR environments might 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 kinds of interactions could be supported in XR for novice versus expert gardeners?
- What is the degree to which users may benefit from XR technology for collaboration in the garden?

To answer these questions, we conducted two studies with 27 gardeners. In Study 1, we used storyboards and experience prototypes to elicit participants' attitudes towards remote gardening and identify the types of interactions important to teaching and learning in the garden. From Study 1, we identified three types of expert-novice interactions: instructing, observing, and discussing. For Study 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 Study 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 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, such as supporting *orientation* in terms of the three-dimensional garden space and in relation to the sun as key for observational interactions. Our second contribution is in identifying a key role for XR to support in 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 and challenges and opportunities for the practitioners when inferring information or conveying the effects of their actions.

2 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.

2.1 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 [17,20]. In-person collaboration provides a shared visual space [30] with fewer constraints on how participants communicate through verbal or non-verbal cues (e.g., gestures, facial expressions), and simultaneously view and interact with objects in their physical surroundings (e.g., people, tools, 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 [44]).

One major focus of XR research has been to understand how embodied representations of remote collaborators that render their body movements onto an avatar (e.g. full-body, virtual hands) 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[8] 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, virtual hands) that enable gesture-based communication (e.g. deictics, metaphorical, or iconic gestures[72]) 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

[53]. Researchers have also considered how sharing embodied emotional cues (e.g., facial expressions, heart rate) during remote collaboration and instruction can improve performance [41,47]. Other interaction techniques, which exist both in embodied and non-embodied XR, include allowing remote users to draw annotations overlaid on a remote or shared virtual environment [1,19,69], representing gaze [2,23], representing the remote environment[42] and objects through 3d reconstruction or virtual replicas [39]. These techniques can allow for improved spatial referencing, over conventional videoconferencing, for instructions during remote guidance.

Specifically, for instruction-based scenarios, embodied practices are being supported in XR environments in a variety of domains [33]. This includes the design of XR systems better aligned with the informational needs of expert and novice surgeons during telementoring [18] and in industrial product design for remote collaborative modification of CAD models [51]. 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, 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[59]. However, learning scenarios are often presented in a manner that it agnostic to the nature of the learning context. The needs of experts and novices in professional settings [18] 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.

2.2 Perspectives on Skill Acquisition

The process of skill acquisition through expert-novice interactions has been approached through multiple lenses in past work. In physical tasks, such as playing a musical instrument, it has been modeled in the past as a function of cognitive demands in different stages of learning [14,17]. For example, Fitts and Posner's 3 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. 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 [36] 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 [40]. 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 [9]. 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 [80]). In the context of informal learning, James Paul Gee [20] 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 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 [13], is important to form the connections required for collaboration and learning in communities of practice [7,11]. 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[41]. While hobbyist learning is characterized by building communal common ground by, for example, 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[13]. 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 the ways in which practitioners perceive XR supporting these interactions compared with conventional video or audio conferencing.

2.3 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 [39]. Interactions between experienced and newer practitioners are key opportunities for sharing knowledge and insights into local sustainable practices and fostering nuanced ethical decision making [50].

Experimentation and observation are frequently mentioned as part of the learning process in gardening [21, 43]. 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 [43]. 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 [44]. 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)[21,39,50]. An example of a design that augments this engagement with nature is Liu et al.' 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 [42].

Perspectives on acceptance of digital tools by practitioners are often an important consideration when deciding to design or "not design"[6]. Handwork practitioners (e.g. knitters and gardeners) are often more forgiving of technology when it extends, interjects, or segments their activity in meaningful ways[21]. 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 [6,25,35]. For example, Heitlinger et al. call for researchers to disseminate knowledge about sustainable practices [25], doing so through co-designing with a diverse group of growers to share their stories combined with networked sensor data from their gardens [24]. Keeping this in mind, we present 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 OVERVIEW OF APPROACH

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

Table 1. Self-Reported Participant Information

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	23	White
E18	Experienced	M	22	Caucasian
E19	Experienced	F	22	White
E20	Experienced	F	18	Asian
E21	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	28	Indian
N6	Novice	M	23	Black

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 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 three phases, 27 individuals participated in the study (see Table 1 for Participant demographics). We intentionally recruited a group that was diverse in age to match the demographics of this activity in naturalistic settings [66], and participants ranged in age from 18 to 80.

Table 2: Session Information

Session	Participants	Relation	Study (Prototypes Used)	Session Location
S1 [a]	E4, First Author	Friends	Study 1 (Storyboards)	E4's home garden
S2 [a]	E2, First Author	Friends	Study 1 (Storyboards)	E2's community garden
S3	E5, E6, E7 E8, E9, E10	Neighbors	Study 1 (Storyboards)	Consecutively split between E8 & E9's two home gardens
S4	E7, N1	Friends, Housemates	Study 1 (XP-2)	E7 and N1's home garden
S5	E11, E12	Friends	Study 1 (XP-1)	E11 & E12's community garden plot
S6	E3, E13	Colleagues	Study 2	E3's community garden
S7	E4, N2	Family	Study 2	E4's home garden
S8	E14, N3	Couple	Study 2	Reserved indoor space
S9	E15, N4	Colleagues	Study 2	Reserved indoor space
S10	E2, E16	Colleagues	Study 2 [b]	E2's Office
S11	E17, E18	Couple	Study 2	Reserved indoor space
S12	E1, N5	Unacquainted	Study 2	Reserved indoor space
S13	E19, E20	Acquaintances	Study 2 [b]	Reserved indoor space
S14	E21, N6	Colleagues		Reserved indoor space

[a] For sessions where we were unable to recruit a novice, the first author (a novice) partnered with the expert.

[b] Due to time constraints, these participants were unable to evaluate the awareness prototype.

Participants had varying self-reported expertise levels that include three master-gardeners[1], four professionals[2], 14 experienced hobbyists, and six novices. In this paper, individuals belonging to the experienced, master gardener, and professional categories are referred to as "experts" and referred to using the notation E#, with novices referred to as N#. 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 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, and insights, therefore, reflect perceptions of US-based gardeners. The outdoor sessions in gardens, for Study 1, were also conducted during the summer and do not reflect seasonally dependent tasks.

[1] 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 be volunteer partners by helping educate other residents to being better gardeners and improve their environmental stewardship. https://mastergardener.extension.org/

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

4 STUDY 1: EXPLORATORY STORYBOARDS AND EXPERIENCE PROTOTYPES

We designed two storyboards and two experience (XP) prototypes to identify attitudes towards 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 [25,34,35]. 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 [21,35,40]. Given the importance of on-site interaction with the garden for developing and teaching this skilled hobby, prototypes all have at least one individual located 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 [35]. Therefore, our prototypes involve scenarios where gardeners can see each other's gardening plots, not just a gardening task at hand, to facilitate these learning interactions.

4.1 Prototypes

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

4.1.1 Storyboards. Storyboarding is a process of describing a user's interaction with a system over a span of time through a series of images with a textual narrative [62]. 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 4 in Appendix A) depicts an informal collaborative gardening scenario, where an experienced and novice gardener have a pre-existing 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 5 in Appendix A). An expert gardener who cannot work due to injury guides a novice through their own 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 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.

4.1.2 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 [75]. Whereas the storyboards helped us understand participant perceptions of different remote interaction scenarios using XR, we conducted experience prototype sessions in order to understand how some aspects of XR might work in practice – specifically, how different configurations within XR (i.e., first-person, shared spatial context) might be used to support skill-sharing. Though experience prototypes have limitations in terms of involving factors that will not be in the real application (in this case, individuals were able to gain certain types of awareness due to being co-located that they could not if they were remote), 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 use a first-person view, from the novice in the garden, to provide mentoring (Figure 1). Many XR systems in professional settings use real-time view-sharing from different perspectives to support remote guidance (see Section 2.1); 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 2). 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 and 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.

Figure 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

Figure 2: Expert instructs a novice transplanting a plant, separated by a virtual window (in red).

Four participants took part in the XP sessions, which lasted 60 minutes each. Prior to 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.

4.2 Key Interactions Identified in Study 1: Instructing, Observing, and Discussing

Findings from this phase are discussed in depth in section 6. 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 study 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 with respect to the ground. The novice plays an active role as well, mimicking the experts' actions when learning the technique or asking questions.

- *Observation:* Experts modeled observation for novices. 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, E7) helped a relatively inexperienced partner (first author, E8, E10, 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 primary components around which we built our prototypes in Study 2.

5 STUDY 2: DEVELOPENT OF XR PROTOTYPES

Study 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 study was to assess how XR could support (or be found lacking) when facilitating these interactions for novices versus experts from Study 1 (Section 4.2). 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 Study 1. However, the participants were allowed to use the virtual garden in XR in an open-ended manner and encouraged to think out aloud, speak to each other, and ask questions in a way they might normally 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.

5.1 Design and Technology Choices

We scoped and designed three prototypes from the key interactions (instruction, observation, discussion) and their associated activities that we had identified in Study 1. We were motivated in understanding 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.d). This design choice was sufficient for us to better understand the impact from our previously highlighted interactions elicited from Study 1.

- We focus on the interpersonal interactions between participants using first-person view-sharing as in recent remote-instruction systems (e.g. [27]). This design also avoids participants overfocusing on the look/feel of an avatar, where prior research has already identified issues such as uncanny valley effects [38].
- 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 suitable for gaining a broad view of perceptions and use of XR in a way that matches many informal hobby-levels needs suitable for 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 in 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 (bandwidth, audio transmission). This set-up 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 represent them as virtual hand movement 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, using the categorizations suggested in prior work [28].

5.2 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, 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.a) is centered around the key interaction of *instruction* that we saw experts engage in Study 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 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 Study 1's group gardening sessions, novices could use virtual hands linked to their controllers' movements. A drawing tool (Figure 3.a) 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 novice while also being able to view their XR-related actions (e.g. lines drawn, virtual hand movement) overlaid on their environment.

5.3 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 and what to pay attention to. They are pointing out elements that, in their experience, require inspection (e.g. weeding, plant health) but could be overlooked by the novice gardener (assumed on-site).

Prototype Description: This prototype (see Figure 3.b) is centered around the key interaction of *observation*. We learned in Study 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 Study 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 eye. 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 and photograph the elements in the scene using a virtual camera. The camera and drawing features provide a way for the expert to detail their process of observation, 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.

5.4 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.c) as an instance of a *discussion*-based activity. Planning the layout of a garden is 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 study 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 grasp a virtual spade to "plant" three types of virtual plants (sunflowers, tomatoes, 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.

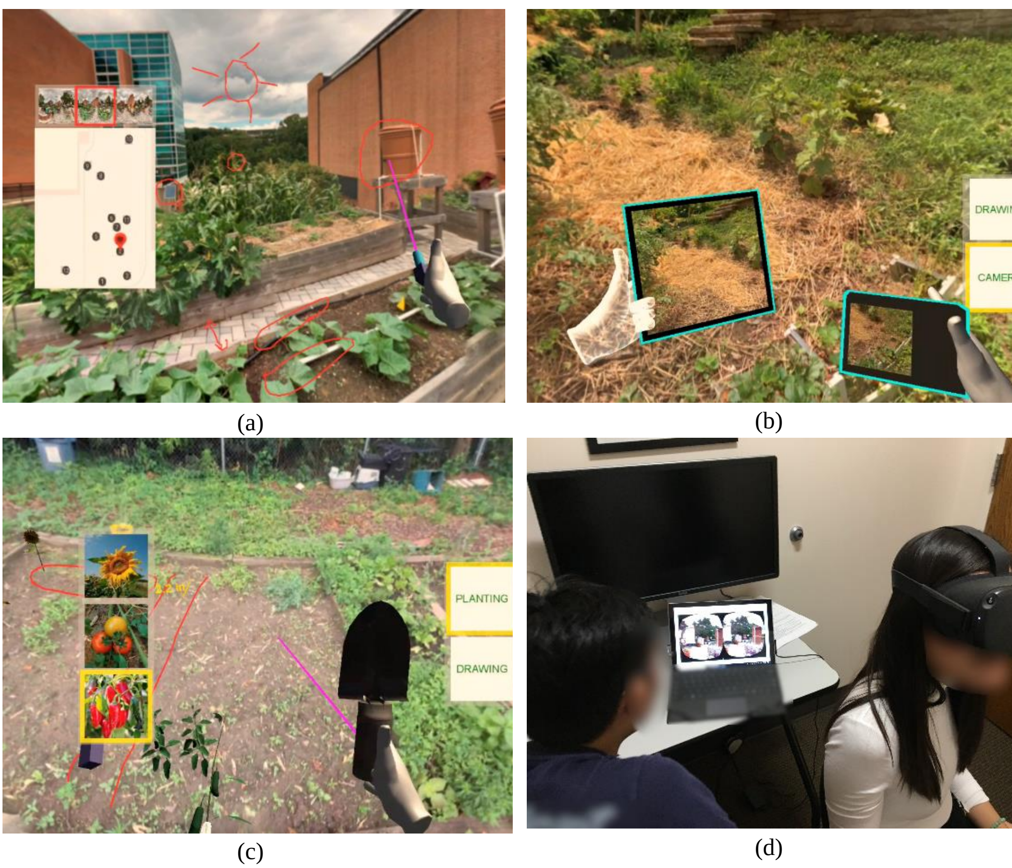

Figure 3: a) Expert Tour prototype screenshot. The novice can draw or point at objects or orient themselves with a map. b) Awareness prototype screenshot showing how the novice can capture photos using the camera tool. The photos preserve a view of the environment for the novice to take note of and become aware of changes over time. c) Garden Planning prototype screenshot. In dialogue with the novice, the expert selects a plant to place in the plot or draws garden boundaries. d) Experienced gardener E14 (viewing the laptop) and novice gardener N3 (wearing the Oculus HMD) dyad from session S8

Table 3: Summary of interaction elements for the remote user of XR prototypes in study 2

Prototype (Key Interaction)	Remote User (VR HMD)	Local User (AR using 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 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 expert to take snapshots of elements that may change over time **Drawing Tool** for expert to annotate the 360 scene and detail their process of observation Virtual Hands
Garden Planning (Discussion)	Expert	Novice	**3D Plant Models** for expert to help visualize a specific plant during planning **Drawing Tool** for expert to mark positions or layouts in the scene Virtual Hands

5.5 Evaluation of XR Prototypes

In Study 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 (Fig. 1.d) --- whether the novice or expert wore the VR HMD depended on the prototype (See Table 3). The participants then spent 15 minutes working through each example activity and were 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 prior to 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.

6 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 [10] 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 [76,77]. First, the first author transcribed the audio from the recordings for further familiarization with the data. For both Study 1 and Study 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 and 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 and 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.

6.1 Perspectives on Remote Gardening

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

6.1.1 Hesitant but open to remote instruction in the garden. As we engaged participants in discussion using our prototypes, we learned of 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 Study 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. And two individuals 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 study 2, E15 felt that she might have been more comfortable with guiding someone remotely "*if we had a computer screen*" and 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]*".

6.1.2 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 facilitated in XP-1 (video call prototype) to be appropriate for instructional tasks where the expert E7 was *"directing it myself"* and telling the novice "*exactly what to do*". In 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 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 (what might be accomplished 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 the 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.

6.2 Skill-sharing interactions using the XR prototypes

Here we describe findings on how the prototypes from Study 1 and Study 2 supported or lacked in their capability to facilitate the key interactions we described in Section 4.2.

6.2.1 Instructing using an XR system. Participants used their bodies as part of the instructional process in almost every Study 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 demonstration 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, 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. One such detail was that while considering spacing on the horizontal plane through the 360-view was possible and useful (e.g., for planning plants in a garden), there was no depth supported, so it was not possible to show how deep to plant. 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 that we built were also less flexible than tools used in in-person demonstrations and were based on some assumptions on the designers' parts: 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 actually experiencing the virtual tools and environment in Study 2 led participants to more deeply consider their ability to instruct in XR and the complexity of designing digital tools.

6.2.2 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 indicate 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 orienting themselves in regard to the position and trajectory of the sun. The first action performed by experts in all nine garden planning sessions (S6 to S14) of Study 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, 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, S13) and to check for fruits that may have ripened under the foliage (S6, 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 spatio-temporal trends, such as by allowing the gardeners to envision a spring garden in the Fall. These findings bring to fore the dynamic nature of the garden space, the challenges, and opportunities that this raises for XR environments.

6.2.3 Discussion between the practitioners. Discussions between the participants often involved making decisions together based on both the expert and novice's inputs. In Study 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 suggests something that her own neighbor had planted and "*won the beautification contest in [locality]*". The expert will 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 6.1.1, 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, which was part of Study 1, 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 available) 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 virtual plants didn't exactly fit the age of the plants he was trying to help N6 visualize.

6.3 Connecting Interactions and Emotional Dimensions

Above we discuss the way the three interactions we identified in Study 1 were or were not supported in XR. Here, we discuss a finding that emerged once we had completed both two studies: an additional interaction type that appears to be key for hobby skill-sharing. In this section, we describe 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 both Study 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 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, regularly connecting 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 are 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 Study 1, rather than just a first-person view, was one of the points discussed. Many of the Study 1 participants 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 Facetime."* However, despite the system being preferred over alternative communication platforms, E2 mentions that it wasn't as easy to share sensory aspects that are easy 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 Study 2, with E14 trying to share a virtual flower across realities from VR into the "*real world*" with his girlfriend N3 during a garden planning in S8, as well as in other sessions (S6, S7, 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, E4) that could provide visual aids and augment the sense of connection to the virtual environment.

Finally, we observed that the sessions in Study 1 yielded more instances of participants connecting with other gardeners by sharing past personal experiences with the activity than in Study 2. This might have been due to the sessions taking place in participants' own physical gardens in Study 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 6.1.1 and 6.2.3, might have also caused participants to tend to instruct and observe more compared to discussing and connecting.

7 DISCUSSION

Through two studies 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 the practitioners when inferring information or conveying the effects of their actions in an XR representation of 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.

7.1 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[6,31]. 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 skill-share in person in the garden, they will likely choose this, but if they lack nearby practitioners with expertise, as in [15], or have specific distant loved ones who they would like to garden with, remote skill sharing may be useful. Remote XR could provide different challenges and opportunities for experts and novice 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 with 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 use 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 6.1,2, these can be easily accomplished via just video communication. Past work interaction frameworks for remote guidance, like Kasahara et. al's Ghost-Body framework [29], and Gauglitz et. al [19] have extend 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 orient 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 miniscule compared to the size of the activity space or even hidden. For this purpose, collaboration with the onsite to perform hand-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. haptic actuator for texture[73]) is an approach that might add value for instruction through XR for either an expert or a novice. Given our participants' perceptions on 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 [43,52]. Another perspective on whether adding precision to an XR environment by digitally mediating the missing sensory information, purely for better instruction or observation, is if would even be considered necessary for an informal hobbyist setting. Do experts or novices in this setting care about that level of precision? We found there was some robustness to mistakes built into the learning in the garden depending on task complexity and where 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 for 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 [16]. As two concrete potential use cases, participants attempted describing the movement of the sun over time from east to west of the plot when planning where to plant something, and the idea of teaching novices to recognize signs of damage by specific pest by simulating this over time on the virtual models of plants in the garden planning activity from study 2. The ability to orient oneself and move one's head to trace the sun through the sky, or to move closer to or interact with a plant are key characteristics that would differentiate these cases from what is possible with simulations without XR.

7.2 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[13]. 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 [21,25,34,35] and other hobbyist communities such as in makerspace and DIY cultures where artifacts can be created to drive discussion and reflection[58,63]. While onsite interaction for this purpose with physical artifacts is viewed as the ideal in these studies, our findings also indicated that XR has potential to augment remote connecting interactions between practitioners that builds 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 Study 1 when compared with the relatively less familiar setting of the XR prototypes in

Study 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 the 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 [35] or by gifting a hand-knit sweater [21]. 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 with making familiar remote objects shareable and interactable virtually (e.g. arranging or reshaping together), for example, with a "memory object" [35] that holds personal meaning in the garden. Given that learning in gardening is often an intergenerational activity[66], there is an opportunity to leverage past work, such as digitalizing physical mementos for intergenerational storytelling [32] or creating a 'magical' experience that triggers meaningful memories through remote, XR augmented spaces [65]. 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 was 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 case 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, participants, both experts and novices, who used our XR prototypes 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 session, 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 [49] 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.

8 LIMITATIONS

This study has several limitations. First, the XR prototypes for Study 2 did not have a physically implemented augmented or mixed reality component (AR/MR) for the local user in the garden and uses a 360-image virtual garden to simulate this. Considering the challenges for an outdoor, dynamic environment with changing conditions (we noted significant variability during Study 1 in internet connectivity and found that outdoor lighting conditions negatively affected our VR HMD's tracking capability), an AR/MR interface will allow a more in-depth understanding to 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 would also be an important consideration 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" (dyads with one partner with significantly more expertise, even when the less skilled partner has some experience), 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.

9 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 two studies, 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 dimension of connecting to build common ground with other practitioners and one's environment. It is also important to facilitate meaningful sensory interactions with 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.

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A STORYBOARDS USED IN STUDY 1

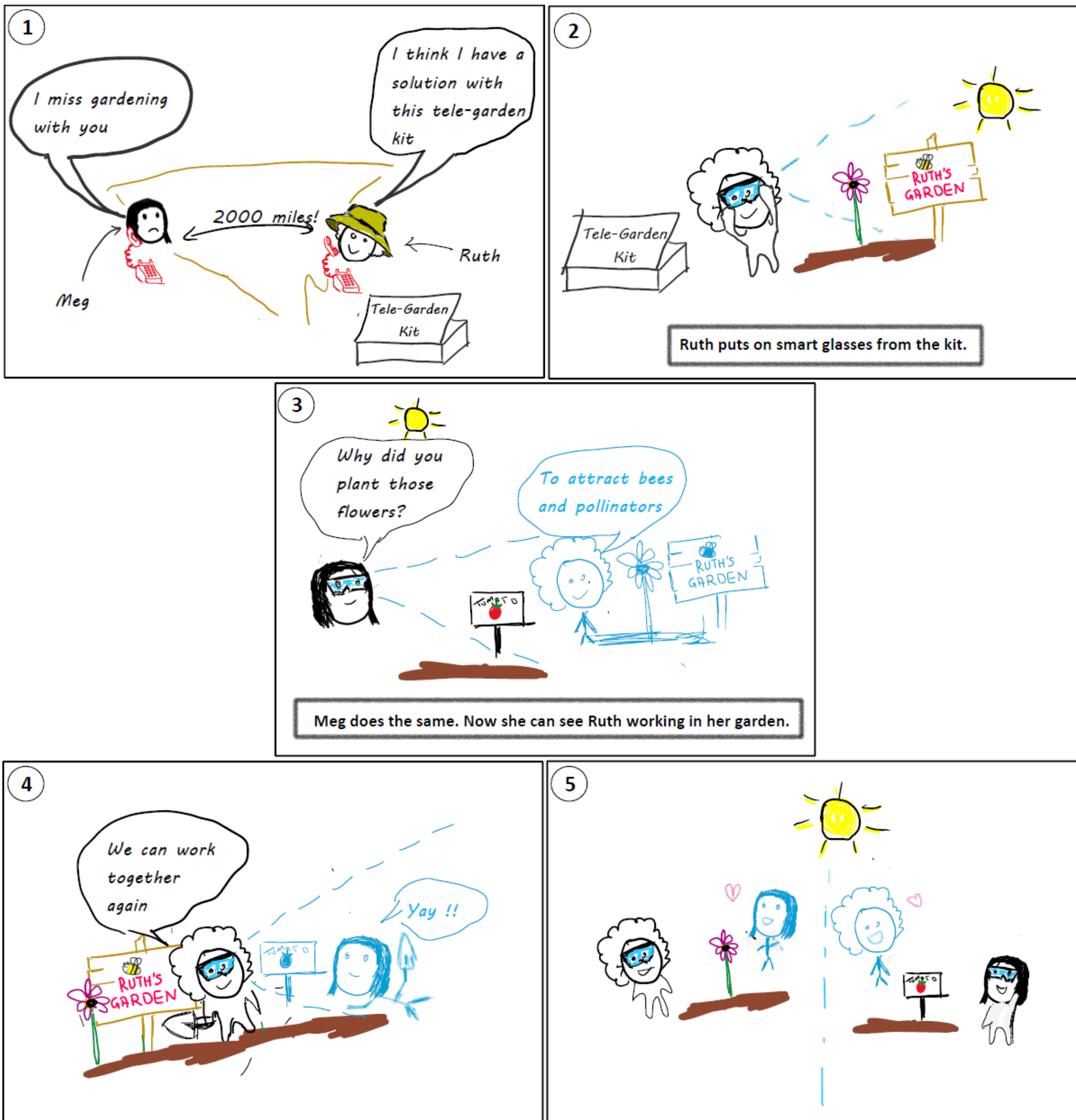

Figure 4: Panels from the collaborative gardening storyboard

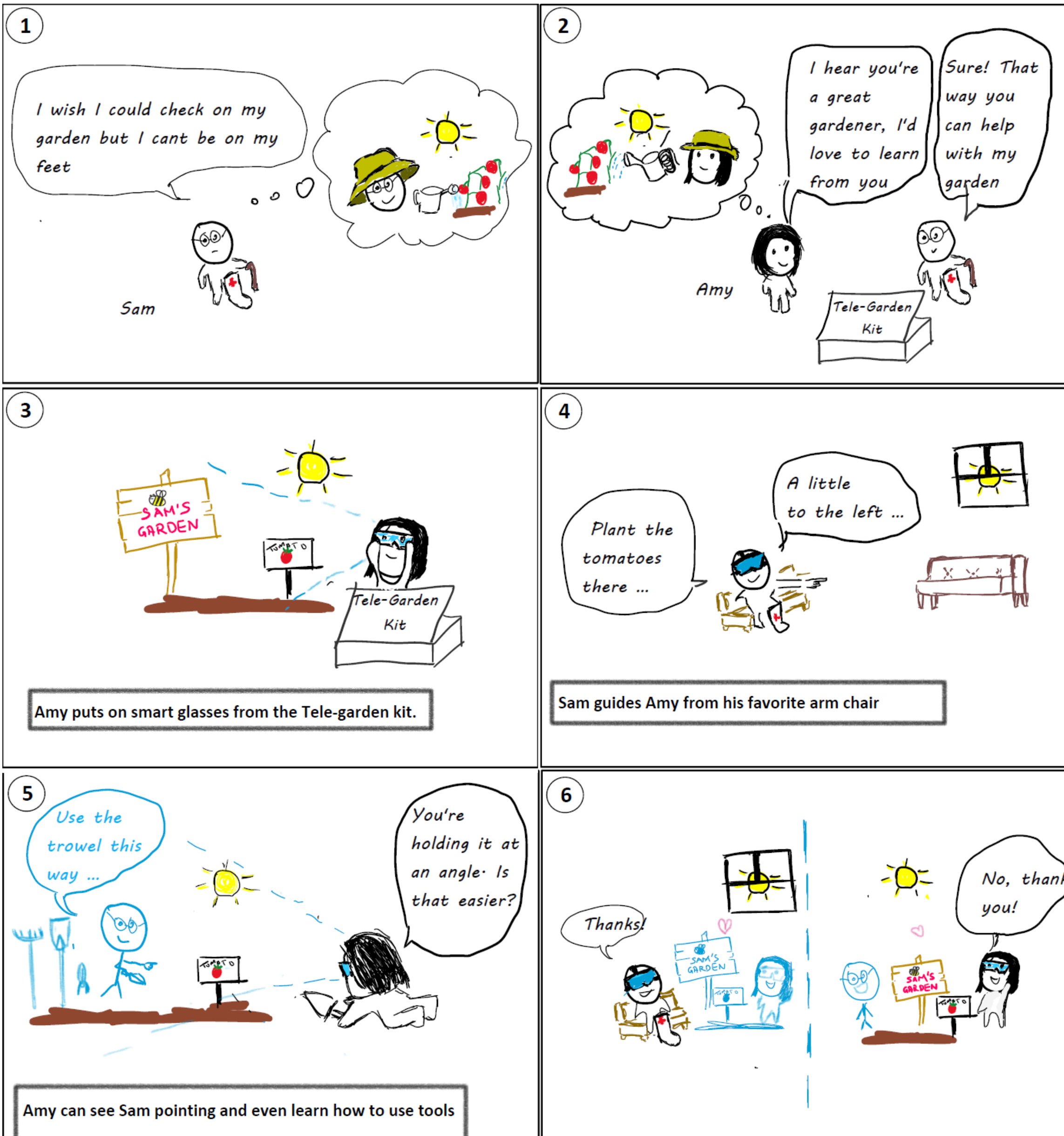

Figure 5: Panels from the expert mentor storyboard