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# Psychological Ownership in Teleinstructive Augmented Reality Workspaces

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Psychological ownership over virtual and physical spaces in augmented reality can lead to tensions between collaborators, yet, there is still a significant challenge in understanding how psychological ownership manifests in shared AR and what that might mean for the inclusion of collaborative interaction mechanisms. Through an experimental instruction task with a teleAR system, we interviewed 16 participant pairs on their perceptions of ownership of virtual and physical spaces and how they thought their perceptions impacted their interaction within those spaces. Our findings indicate (1) how AR introduces new ideas around behavioral norms in spaces that are layered and (2) that the nature of the task itself, in this case one of instruction where collaborators have different levels of knowledge and the local worker is reliant on the remote expert, significantly affects the perceptions of ownership and therefore behavior norms.

CCS Concepts: • **Human-centered computing** → **Empirical studies in collaborative and social computing**; *Mixed / augmented reality*.

Additional Key Words and Phrases: augmented reality, remote instruction, shared information, territoriality, social interaction

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## 1 Introduction

Shared Augmented Reality (AR) environments, where two or more people experience and interact with the same virtual layer [3, 39], can increase non-verbal communication [3] but also can incur interpersonal tensions because of privacy [9] and personal space concerns [37]. The reason for rising interpersonal tensions in shared AR is partially explained by the experience of psychological ownership over the virtual and physical spaces in the environment. One can become emotionally invested in a space for which they have a strong sense of psychological ownership [21, 38]. In turn, the forms and access to interactive functionality can have a great impact on that sense of psychological ownership. For instance, when there is the ability to have joint customization of virtual objects, both participants develop psychological ownership towards that object [8]. Therefore, if there is a difference in perception of the psychological ownership of objects between the

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collaborators, this could further hinder interaction with the virtual objects, affecting communication and collaboration. For example, a study on collaborative music playlists found that participants felt uncomfortable deleting songs added by others. This discomfort was linked to underlying social norms and fear of harming social relationships [29]; as people feel a sense of ownership over objects and spaces, their behaviors signify that sense of ownership and are impacted by the social rules and norms around ownership. This resulting behavior of psychological ownership has commonly been referred to as *territoriality* in the CSCW literature [20, 27, 43].

Although studies of psychological ownership in an individual's interactions in AR have arisen in recent years, there is still a significant challenge in understanding how psychological ownership manifests in *shared AR* and what that might mean for the inclusion of collaborative interaction mechanisms. Notably, the few studies of psychological ownership in shared AR have investigated co-located collaborators [35, 37], but have not delved into the popular use case of AR used by those that are in *distributed* environments to communicate or collaborate with one another — i.e., *teleAR*. The unique way that AR incorporates a remote user's virtual objects into the local user's physical world raises the question of how users will perceive the ownership of the shared AR space and thus interact within that space. If we are to realize the vision of highly coupled collaboration in *teleAR* [23], then we must address psychological ownership which can lead to tensions in shared AR [37].

In the following study, we investigated (1) how users of *teleAR* perceived the ownership of virtual and physical spaces during an instructive task and (2) how users thought their perceptions impacted their interactions within those spaces. We investigated these phenomena with a local worker completing a building-blocks task via the instruction of a remote helper utilizing a head-mounted *teleAR* system. We show that users have fairly agreed upon perceptions of psychological ownership of the physical and virtual interaction spaces but do not have a clear agreement on who owns a shared view although they do agree that ownership is not shared. We also show that the users' perception of ownership of the various physical and virtual spaces were highly influenced by the nature of the task: instruction in this study's case. We present a layered model of shared AR spaces that elucidates the factors that led to perceptions of ownership and norms of behavior in those spaces as well as the moderating affect of the collaborative task type. We compare these findings to prior research on psychological ownership in virtual environments and provide some suggestions for future research on psychological ownership and *teleAR* broadly to better understand the impact of task type on the layered model of psychological ownership in shared AR.

## 2 Related Work

### 2.1 Instruction with TeleAR

In a remote instruction scenario, a remote helper, who may be an expert, provides guidance to a local worker on how to directly manipulate objects. For instance, a remote specialist helps a local paramedic to provide patient care [30]. AR applications have been proposed as solutions to improve a remote helper's understanding of the local work environment by sharing the point of view of local workers through AR Head-Mounted Displays (HMDs) in real-time [15, 40, 42] and providing virtual tools for remote helpers to annotate the local environment. In such a shared AR workspace, digital AR objects can be superimposed directly on the physical working space, so collaborators need to coordinate between physical objects and AR objects in the shared workspace. For example, a remote helper can place virtual annotations to highlight specific areas in a local worker's environment and the local worker manipulates physical objects while viewing the AR annotations [13]. Inherently, in those systems, the degree to which the remote helper and the local worker can control is different between virtual and physical objects, and this determines how the pair communicates and

collaborates. The remote helper can only interact with the physical environment by instructing the local worker, because they cannot control physical objects, while the local worker only observes virtual guidance from the remote helper, without being able to manipulate this digital information. That is, there is a fundamental gap between digital AR information and physical tasks because each role has a different level of interaction with digital and physical objects, and it can be inferred that this is the difference between the virtual and physical worlds that limits collaborators to perceive and understand shared information [52].

## 2.2 Overlapping a Digital Workspace With Physical Workspace in AR

The advance of AR technology enables a remote helper to give instructions by pointing or annotating to a physical workspace where a local worker performs physical tasks. It seamlessly integrates the digital instruction system and actual physical tasks, and expands the ability of digital information to describe the physical world [52]. Kim et al. [18] proposed a remote collaboration system that provided an independent view or a dependent view of a shared workspace to a remote user. In their system, a brown tetragonal border was overlaid to represent the area of their collaborator's view. They indicated that remote users felt more together and had a better understanding of their local partners because of the explicit representation (the brown tetragonal area). Gurevich et al. [15] also demonstrated a collaborative AR system, in which a green rectangle to denote the AR working area was projected. The projected rectangle was implicitly designed to inform the local worker where the AR annotations could be placed. Fang et al. [10] developed a shared virtual whiteboard where the remote helper can point and annotate in a viewport of the local worker wearing an AR HMD. Through the whiteboard, the remote helper was able to transfer their 2D information on a monitor to the local worker's 3D environment. They showed that their AR system improved the accuracy of execution of tasks, and the AR system was more supportive while guiding inexperienced local workers in simple tasks. Through the use of a real-time AR space, remote collaborators establish a common ground analogous to their understanding of the physical space by highlighting particular areas of interest or sharing situated information associated with pertinent objects in the on-site physical environment. Fussell et al. [11] explored the benefits of shared visual information for collaborative repair tasks with HMD-based video and audio systems. They showed the shared visual space is essential to facilitate conversational grounding and suggested design guidelines such as a wider field of view and gesture interaction for better video-based systems. Poelman et al. [34] also introduced a novel AR HMD system, specifically designed to support crime scene investigation collaboration between on-site investigators and remote experts, by implementing a dense 3D map to reconstruct the crime scene. Notably, the system facilitated a mutual understanding among participants, with visual feedback and the visibility of actions playing a crucial role in achieving a shared perspective on the analysis. However, those studies have been focusing on the performance of collaboration by AR objects in a situation where the digital workspace manipulated by the remote helper overlaps with the physical workspace of the local worker while leaving notions of psychological ownership aside.

## 2.3 Psychological Ownership and TeleAR

Psychological ownership, a multi-dimensional construct, gains added complexity in teleAR contexts [32, 35]. As Poretski et al. [35] have delineated, five key dimensions define psychological ownership: possession, control, identity, responsibility, and territoriality. These dimensions acquire new layers of interpretation within the realm of teleAR. Possession, the most fundamental dimension, represents the feeling of having something or the sentiment "this is mine" [33]. Poretski et al. [37] found that the feeling of possession can be jeopardized when virtual elements are overlaid on physical items without explicit permission. Such unauthorized actions are perceived as invasions

into one's personal space, affecting the quality of communication experiences. Control refers to the ability to influence, manage, or manipulate the owned object or space [2, 28]. In a teleAR, this could involve moving and modifying virtual objects, thereby influencing the shared virtual environment. Lanir et al. [19] revealed the importance of control over the point of view in remote assistance, suggesting that control should ideally be in the hands of the helper when most of the knowledge resides there. Identity signifies the extent to which the owned object or space becomes a part of the individual's self-concept [2, 7]. For instance, Avey et al. [2] found that the formation, maintenance, and transformation of one's self-identity are deeply intertwined with both tangible and intangible possessions. These possessions, or targets of ownership, often serve as markers that define one's self-identity, such as identifying with a particular profession. Furthermore, in organizational settings, this sense of ownership can facilitate a deeper connection and sense of purpose within the organization, enhancing feelings of significance and community. Responsibility involves a sense of obligation or stewardship towards the owned object or space [2, 28, 51]. According to Poretski et al. [36], possessing something inherently implies a sense of responsibility to protect and defend it. Territoriality represents protective behavior toward the target object or space, and the tendency to defend it from others [6, 41, 49]. For instance, territorial behaviors can emerge in Wikipedia even when cultural norms discourage ownership. Participants in the study still staked claims and set boundaries on their contributions for quality assurance, using existing platform features [49].

These dimensions are interrelated, and their interactions can significantly influence the instructional dynamics. For instance, a strong sense of control over AR elements may enhance feelings of possession and responsibility among remote users, affecting their willingness to adapt based on worker's feedback [35]. Also, Carrozzi et al. [8] revealed that the customization of AR holograms could foster a sense of psychological ownership over digital objects, suggesting that AR functionalities allowing for personal customization can significantly influence psychological ownership. The study also highlighted the mechanisms of social adaptation related to assimilation and differentiation that drive the relationship between customization and psychological ownership of AR holograms in social settings. Moreover, a shared sense of psychological ownership can develop when both parties engage with the same instructional elements. This collective ownership can lead to enhanced collaboration through a mutual sense of responsibility but can also spawn territorial conflicts [25, 31].

## 2.4 Territorial Behavior in Shared Workspaces

Collaborations in shared workspaces, in general, are well-researched in computer-supported cooperative work (CSCW). One of the theoretical frameworks regarding shared workspace is territoriality. "Territorial behavior is one of the ways in which psychological ownership manifests itself in social interactions" (Avey et al. [2]; Brown et al. [5]). According to the territoriality theory, territories support people to mediate their social interaction through claiming and coordinating spaces [1]. During collaborative activities, collaborators divide the shared workspace into areas for different purposes. These spaces typically allow for efficient use of available space [48]. Scott et al. [43] investigated how people coordinate their workspace in tabletop collaboration, thus they revealed three types of territories: personal, group, and storage. A personal territory is typically an area that proximately surrounds the person, and is reserved by that person to ease their actions. This territory is visible but not accessible to others most of the time. Social norms of privacy come into play here; entering someone else's personal territory is often viewed as an invasion of privacy that requires explicit permission [27]. A group territory is an area where collaborators share access to perform tasks and is often centrally located to facilitate collective input. This territory serves as a dynamic space where objects or papers are moved to the center for group discussions. Here, unspoken rules of turn-taking and group dynamics often come into play, with some members even assuming

roles as mediators or leaders to coordinate collaborative actions [20]. Lastly, a storage territory serves as the area to store task resources and non-task items. This zone is usually at the periphery of the workspace and is used by collaborators to organize resources that may be needed later. Participants often engage in loosely arranging, piling, and searching items within these territories. Items frequently transition between storage territories and other tabletop territories, depending on the phase of the task [44]. Another type of territory in shared workspaces is the private territory, such as the incognito window of a group member. Rekimoto and Saitoh [39] showed the private and public territories claimed by devices. Private territories are displayed on personal devices, while public territories are displayed on a shared public workspace. In AR remote collaboration, the AR HMD is a personal device but the local worker's view is shared with the remote helper. The remote helper accesses the local worker's physical workspace via AR digital space. This type of AR remote collaboration is different from previous studies such as tabletop collaboration [43] or two-sided transparent display collaboration [22]. Accordingly, remote collaboration using AR shared workspace needs to understand how collaborators orient and partition their spaces to mediate group interactions.

AR systems enable new ways to collaborate remotely, where a remote person can perform virtual actions on a local worker's physical space. The blend between virtual and physical can vary according to the domain and task needs, for example for instruction, a remote helper can point and annotate on physical objects, to instruct on an assembly task. In this case, the virtual pointers and annotations are placed in the physical environment, so the local worker can feel like the virtual objects are physically there. Johnson et al. [17] introduced UnMapped, a collaborative Mixed Reality (MR) system designed to uniquely combine a live 3D view of the novice's workspace with a static 3D recreation of the expert's workspace, leveraging the expert's spatial memories. This approach not only brought the expert's situated experiences into the collaboration but also enhanced performance and communication efficiency. Similarly, Grønbaek et al. [14] proposed the concept of Partially Blended Realities (PBR), supporting remote collaboration where physical spaces are dissimilar. By enabling remote collaborators to partially align their physical environments, PBR tackled the challenge of creating coherent blended spaces for collaboration. However, prior studies [14, 17] have focused on the technical capabilities for spatial manipulation without considering how such interactions affect the collaborators' sense of ownership and territorial behavior over the shared virtual and physical spaces. Given this new blend of physical and virtual, it is important to understand the control and ownership of objects and spaces for the informed design of interactive components.

### 3 Study Methods

The research questions for this study were (1) how users of teleAR perceived the ownership of virtual and physical spaces during an instructive task and (2) how users thought their perceptions impacted their interactions within those spaces. To answer both RQs, we engaged in an interpretive, qualitative research approach investigating user's experiences during a physical object instructive activity. The study was reviewed and approved by the institutional review board at the University of Maryland, Baltimore County ensuring compliance with ethical standards for human subject research. Participants were provided with a comprehensive overview of the study, including potential risks such as dizziness from using the HoloLens2. Our consent form detailed the study procedures, data collection methods, and confidentiality measures. Participants were informed that all audio and video recordings would be anonymized and securely stored.

### 3.1 Choosing a Distributed Shared AR System

For this investigation of psychological ownership in teleinstructional augmented reality workspaces, we needed a teleAR system that (1) allowed for telecommunication including audio and video between a remote helper and local worker, (2) was head-worn for hands-free interaction, and (3) supported instruction of physical tasks. It is important to note that a remote expert behind a computer and a local worker using an AR HMD is a typical setting in distributed AR work. While the remote expert has no constraints and thus can use a classic computer, the local worker needs their hands to perform the physical work. Therefore, they benefit from the AR HMD as it enables hands-free interaction, while at the same time visualizing information from the remote expert in the place of work as a world-stabilized overlay rather than in a separate monitor. We chose the HOLOMENTOR [45], because it leverages the Microsoft HoloLens2 which fulfills the first and second criteria. HOLOMENTOR also satisfies the third criteria as it is an application designed for remote instruction during local worker's completion of physical tasks. Namely, the system provides real-time pointing and annotating (drawing) by a remote helper, which is crucial for providing immediate guidance during remote instruction scenarios [11, 12].

We considered a number of other AR systems including the native Microsoft HoloLens2 app, Remote Assist for HoloLens, but this application only provides pointing/annotation functionality over a snapshot of the live view, limiting the interactivity and real-time guidance. *Loki* [50], a mixed-reality collaboration system that enables users to interact with and annotate both local and remote environments, we felt was unnecessarily complex for this first study as it required two headset users and integrated an AR and VR environment. Similarly, commercial systems like ShapesXR and Spatial, designed for AR-AR or AR-VR collaboration, also required two headset users and did not support real-time pointing/annotating. Although HOLOMENTOR is only one application of teleAR useful for instruction, we chose to start this investigation with a system that did not require two headsets and that provided real-time pointing/annotating with the intention of future studies to investigate how other system instantiations change these findings.

The basis of HOLOMENTOR consists of two parts: a desktop application for the remote helper (Figure 1(b)); and a HoloLens2 application for the local worker (Figure 1(a)). There was a two-way audio and one-way video connection between the HoloLens2 app and the desktop app over a local WiFi network. Video was captured using the HoloLens2's world-facing camera and streamed to the remote helper's application enabling the remote helper to see the environment the local worker is looking at in real-time. In the following subsections, we highlight the important functionality of the HOLOMENTOR system that may have impacted psychological ownership. In the analysis that follows, the authors pay close attention to these design choices being referred to by the participants in their discussion of ownership.

**3.1.1 Head Mounted AR Device.** As the HOLOMENTOR utilized the HoloLens2 device, the video that was captured, streamed, and ultimately interacted upon by the remote helper was always from the local worker's point of view. In addition, any interactions by the remote helper over that video — i.e., pointing, drawing, and erasing — were displayed directly on the view of the local worker. Thus, they were never given the choice to allow or remove such interactions and their view of the workspace may be compromised by any overlays.

**3.1.2 Actionport.** In order for the remote helper to be able to draw on live mobile views, the HOLOMENTOR entailed a virtual space called the Actionport (see Figures 1(a) and 1(b) for images indicating the Actionport overlay). The Actionport is placed by the remote helper in a fixed position as a virtual overlay in the local worker's physical environment.

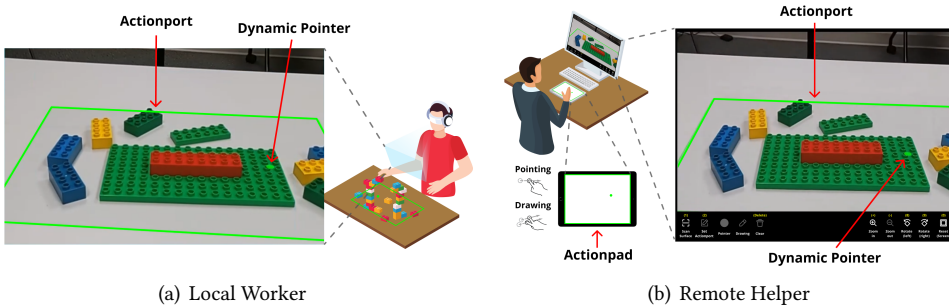


Fig. 1. Overview of HOLOMENTOR. (a) A local worker wears an AR HMD while performing a physical task. They see a world-stabilized, 2D Actionport (green square) overlaid on their physical workspace. Within the Actionport’s boundary, the remote helper’s annotations and pointer are displayed (the pointer is a green dot on the right side of the green flat building block plate). (b) A remote helper sits in front of a computer display and uses the Actionpad to point and draw in the Actionport (Reproduced from Seo et al. [45].)

3.1.3 *Placement of the Actionport.* In order to facilitate remote and local worker coordination in the placement of the Actionport, HOLOMENTOR provided a feedforward mechanism (a visual affordance used to convey to users what possible interactions are and what to expect). The feedforward mechanism enables both collaborators to preview where an Actionport will be placed by using a raycast along the local worker’s head direction (Figure 2). The remote helper then pushes a button on the remote desktop application’s toolbar to affix the Actionport to the area shown in the preview. An Actionport is then displayed as a green rectangle in the shared workspace seen by both the local and remote helper (refer back to Figure 1(b)). Once the Actionport is placed, the remote helper’s pointing functionality is automatically activated. Note that the remote helper cannot move the position of the Actionport themselves, they can coordinate with the local workers to place the Actionport through this feedforward mechanism.

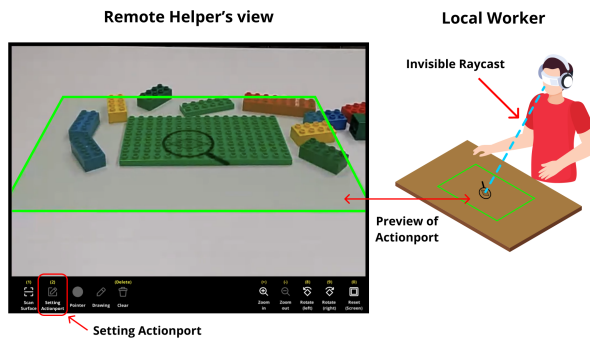
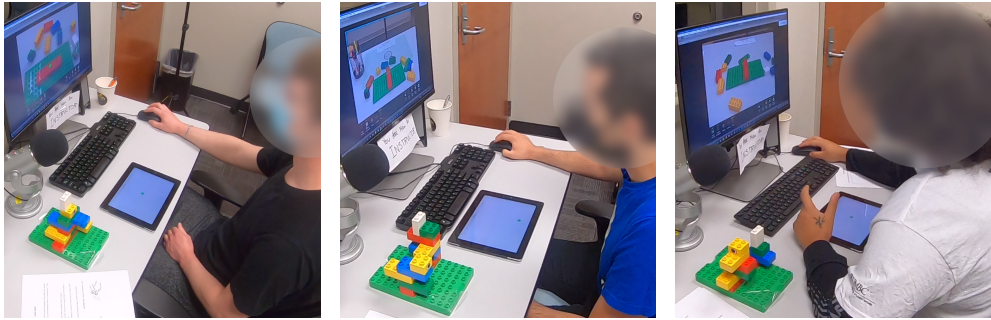


Fig. 2. Demonstration of the raycast for placement of the Actionport. (Reproduced and updated from Seo et al. [45].)

3.1.4 *Pointing & Annotating Functionality via the Actionpad.* The HOLOMENTOR’s desktop application provided the remote worker with the ability to point, annotate, and erase annotations within the bounds of the Actionpad. The local worker did not have the digital functionality to point, annotate, or erase annotations. In addition, all pointing and annotating by the remote worker were





(a) Task Setup for Remote Helper (*P3*) (b) Task Setup for Remote Helper (*P5*) (c) Task Setup for Remote Helper (*P8*)

Fig. 3. Remote helpers' setups and pre-built structures. (a) *P3*'s workspace and final model. (b) *P5*'s workspace and final model. (c) *P8*'s workspace and final model. Each image shows the unique pre-built structure that the remote helper used as a reference for instructing the local worker.

enacted in real-time - in other words, they could not, for instance, draw and then share that drawing with the local worker. In order to point and draw accurately on the Actionport, the HOLOMENTOR system provided a tablet called the Actionpad. The tablet face's rectangular boundaries represented the Actionport's rectangular boundaries and so when moving one's finger on the tablet's face the HoloLens' pointer would move in the corresponding XY coordinates in the Actionport. To move a pointer, a remote helper touches the touchscreen with one finger and moves it over the surface in the XY plane, and to draw, the remote helper touches the touchscreen with two fingers and moves them in tandem over the surface.

### 3.2 Participants

A total of sixteen participants were recruited through targeted email solicitation to undergraduate and graduate students in the College of Engineering and Information Technology at UMBC across 10+ programs. As participants replied stating their interest in participating, we simply paired them based on their availability. This method of recruitment and assignment resulted in a random pairing where participants did not know each other. All of our participants were between 18–30 years of age, of which four identified as female (*P1*, *P7*, *P9*, and *P11*) and twelve as male and none had any prior experience with the Microsoft HoloLens2. Each participant was compensated with \$20 for their time and effort. As this is an experimental study, we had to make some *a priori* decisions regarding sample size. As Scott et al.'s [43] first study of territoriality had 18 participants, we felt meaningful findings would emerge from a similar sample size. We thus stopped recruiting when we reached 16 participants and decided to further recruit if that proved to not be the case. During our analysis as outlined below, we quickly reached the point where no new information was discovered and redundancy of findings began to occur indicating that we had reached the saturation point typical in qualitative research, and thus did not need to recruit further participants.

### 3.3 Procedure

Each participant was placed in a separate room. The participant who first played the role of the remote helper sat in front of a desktop computer and provided a mouse, keyboard, and the Actionpad tablet. The participant who first played the role of a local worker sat at a table and provided with the HoloLens2 AR glasses.

After consent was attained, each participant watched the same introductory presentation that outlines how the system worked (e.g. how to set the Actionport, how to use the Actionpad) and how HOLOMENTOR could be used for remote instruction. After completion, the participants then engaged in a practice task with HOLOMENTOR. The remote helper was provided with a drawing of a house and a guide that ensured the participants would gain experience in using each functionality at least once. The local worker was provided a pen and a plain sheet of paper. During and after the practice task, both the participants were free to ask any clarification questions to the researchers. The practice task took about 10 minutes. The participants were then introduced to the main task: building a block structure. The remote helper was presented with a pre-built structure situated on a baseboard. The baseboard was fixed to the table such that the remote helper can view the structure but not move it in any direction. The local worker was presented with several building blocks and a fixed baseboard in front of them. Specifically, we provided 10 blocks and one base plate to the local worker, while the remote helper was given a pre-built structure (see Figure 3 for screenshots of the task setup and final structure) using the same set of bricks. We manually constructed a new structure for the remote helper at the beginning of each session utilizing the same blocks across sessions, ensuring a unique challenge for each pair while maintaining a consistent level of complexity. Additionally, both the remote helper's and local worker's baseplates were fixed in position to provide consistent starting points and orientations. For the local worker, we placed a large red brick as an initial reference point, further enhancing consistency in the task setup. When the main task began, the remote helper instructed the local worker using HOLOMENTOR. The communication between the remote helper and the local worker to complete the task was accomplished solely by using the HOLOMENTOR's two-way audio channel, video from the AR HMD system, and augmented reality visual overlays. The participants then switched rooms and thereby switched roles. Another practice task was completed with a different drawing, followed by the main task again. For the second round of the main task, a different building blocks structure was assigned to the remote helper to avoid a learning effect. Each of the main tasks lasted approximately 15 minutes.

Lastly, a semi-structured interview was conducted where the researchers and both participants gathered in one large room. The interview contained questions from what the researchers observed during the main tasks and other questions from an interview script (see section 3.4). Each participant took turns to answer each question in their role as a remote helper and a local worker. The post-activity interview lasted approximately 20 minutes.

### 3.4 Data Collection

*Post-Interview:* After participants performed the two main tasks, the researchers and the participants came together for an interview that was audio recorded. The interview consisted of semi-structured questions as well as follow-ups and additional questions added from what the researchers observed during the main tasks. See [Appendix A](#) for the Post-Interview Guide; however as this work was interpretive, the guide was simply there to ensure we touched on all concepts and there were also many follow-ups and opportunities for participants to expand on their thoughts.

*Audio-Video Recordings & Researcher Notes:* The interaction between participants during the main task was audio and video recorded using GoPro cameras in each room and using a screen recorder software to capture the use of HOLOMENTOR on a desktop. The placement of the cameras captured the desktop application's display, the interactions with the Actionpad, the profile of the remote helper, and the upper body and workspace of the local worker. The researchers also took observation notes during the main task.

### 3.5 Data Analysis

The interview data was analyzed with inductive coding and interpretive presentation of the findings [26]. First, the interview recordings were transcribed using Otter.ai<sup>1</sup> and manually checked for missing data. The first author then inductively open-coded the transcribed data in NVivo regarding perceptions of psychological ownership and perceptions of resulting behaviors. In particular, we identified who the users felt controlled and/or who had responsibility for a space as well as how they thought that ownership affected their interaction with the spaces and one another. Note that in accordance with interpretive qualitative analysis, the coding process was a mechanism for taming the data and not a definitive quantitative measure of the occurrence of perceptions [26]. These codes and related quotes were then shared with the other two authors for collaborative interpretation and implications. We also returned to the video recordings to verify that the behaviors recounted by our participants were accurately recalled, as well as to further interpret and support our interview analysis. However, as we were interested in perceptions of psychological ownership, i.e., internal cognition that is not observable, we did not analyze the observable behavior for this paper. We present our work and the findings in accordance with interpretive qualitative methods standards [26, 46].

## 4 Findings

In the following, we delve into the ways users of teleAR perceived the ownership of virtual and physical spaces and how those users thought their perceptions impacted their interaction within those spaces. First, we show the differences in perceptions of ownership of the shared view across participants. Second, we present perceptions of interference and its effects on norms of interactions, resulting from the remote worker pointing and drawing in the Actionport which is overlaid over the shared view. Third, we detail perceptions of ownership of the Actionport and how the collaborative task of its placement impacts ownership. Lastly, we present notions of ownership of the physical space, affected by feelings of control and responsibility.

We specifically highlight when design elements of the HOLOMENTOR, including the use of the Actionport, were indicated by participants as a modifier in these perceptions and actions. As evidence, we primarily present quotes from the post-study interviews. In the presented interview quotes, we indicate the group number and participant number of the speaker (e.g., G3P6 for group 3, participant 6). Note that the evidence we present is exemplary of our findings due to space and reading accommodations and, so, is not exhaustive of the existing evidence we identified. Note also that although we will refer to the local worker (LW) and remote helper (RH), we retain the participant's own wording in quotes when they are referring to people and places and add clarification in brackets.

### 4.1 Shared Spaces Does Not Always Mean Shared Ownership

The video that is captured by a local collaborator's head-mounted AR system and transmitted to a remote collaborator becomes a shared view — is a common space for both collaborators who, for the most part, have equal access to view this space. However, our participants had varied perspectives of who owned this shared view. Several participants explicitly articulated that they perceived the shared view as belonging to the LW. This was mainly relayed as being because the RH is unable to accomplish anything without the cooperation of the LW.

Yes, I also think it's [the shared view] the worker's [LW] area, even though the instructor [RH] was controlling everything. But that is inside of my [LW] work area. G3P6

<sup>1</sup><https://otter.ai/>

I feel like the worker [LW] has the ownership of the workspace [shared view] because literally we're just looking through their eyes. Like the instructor [RH] is just giving instructions. So, I feel like the worker [LW] has more power or like more ownership of the workspace [shared view] because I mean like the instructor [RH] is mainly just guiding them. *G8P15*

When prodded further on why participants thought the LW was the owner of the shared view, a common response was because the RH was unable to accomplish anything without the LW being involved.

Unless and until I [LW] share my proper vision of what I have, even though you [RH] may have all the controls and all the buttons and all of that as an instructor, if I don't give you the correct view, field of view, then it's pretty much useless. *G7P14*

The drawing and the pointing is mainly dependent on whether the worker [LW] is looking at the right place. So if that is not even possible then drawing and pointing [by the RH] is like kind of useless. *G8P15*

Thus, generally, the participants clarified that the shared view was owned by the LW because the LW exerted all the foundational control over that space. This was specifically in regard to when and how the LW presented a suitable view for the RH to work with. However, there were also some participants who relayed that the shared space was the purview of the RH, in essence, because the *task itself* was an instructional one, and could not be completed without the RH's input.

It's [the shared view] not the worker's [LW] area blocks-space because he can put the blocks in a different way than what he's instructed. But he's struggling in doing it in a structured way. So I feel like it's more of the instructor's [RH] [space]. *G2P4*

We [LWs] can't do anything without the instructors' [RHs] directions. *G6P11*

I feel like the instructor [RH] has like more ownership because he's the one who is responsible for telling where to put what, even though I have like all the blocks I don't know where to put all the blocks. The instructor needs to tell me like where to put, so for arranging everything, so the instructor has to do everything. So I feel like the instructor has some upper hand in this. *G8P16*

Thus, in comparison to our prior set of participants, these quotes reveal that the task and the responsibility for that task are what define the ownership over the shared space for some users. However, what is noteworthy is that, for essentially all participants, the shared view was never really considered as being shared ownership. The closest we had to a perception of shared ownership conveyed was when one participant said it was due to a handover of ownership of this virtual space due to the task itself.

But yeah, it was more like it was it was his [RH] workspace when I [LW] was watching him tell me where to put something. And then once he was done telling me then it was kind of my [LW] workspace to put the brick down. I [LW] was totally happy just being a cameraman, until he [RH] was done telling me what to do. *G2P3*

In total, from these explicit reflections on who owned the shared view, it seems that the participants do not agree on who owns this particular space although they leaned towards LW ownership. At the very least, what is clear is that the shared view in our shared AR environment was not deemed as having shared ownership, and that factors such as the necessity of involvement, responsibility for the outcome, and task type can all influence this perception.

## 4.2 Norms of Interaction in Shared AR Spaces

In this section we focus on how the norms of interaction in the Actionport impacts the norms of interaction in the Shared View. HOLOMENTOR provides a personal device to the RH, the Actionpad, to be used as a mechanism to interact on the shared view through the Actionport. So, whereas the Actionpad is without a doubt owned by the RH, the result of interaction on that device (i.e., pointing and annotations) is realized in the Actionport that is overlaid on the shared view - a space that was perceived by some to be owned by the LW.

We learned through our interviews that, first, the participants overwhelmingly did not perceive the RH as “interfering” when they were pointing or annotating in the Actionport that overlaid the shared view. In fact, as we see in the following quotes, the participants had strong justifications as to why it was normal and almost expected for the RH to point, draw, and annotate whenever they wanted over the shared view.

Seeing him [RH] drawing, it didn’t [bother me]. I was just like, okay, he’s probably drawing so I could like better understand what I’m [LW] doing. *G1P1*

I [LW] just sat and watched what he [RH] was doing. I felt that my job was to keep the camera centered. I felt like I was more of a cameraman while he was working. And then once he was done doing his part then it was my space to place the bricks. *G2P3*

Considering that what the worker [LW] was supposed to be doing was purely based on the instruction that we got from the instructor [RH] like, I wouldn’t say like really anything got in the way except for like when you couldn’t see because of the drawing on your screen but like nothing that [RH] said got in the way of what I was trying to do because I was doing everything based purely off what she said. So I wasn’t actually doing anything in my space myself, except for just following her directions. *G4P8*

The justifications often cited were that pointing/drawing behavior was for the LW’s benefit and that the nature of the instructional task meant that the RH’s behavior was necessary. Moreso, when participants adopted the position of the RH, the perspective was similar to that of the participants who had adopted the position of LW. In fact, we learned of more justifications and reasons why the RH *had* to draw on the view and thus why such behavior could not ever be deemed as inappropriate.

No, I [RH] didn’t feel like I was interfering. More like I was riding the worker [LW]. I assumed that he was ready to get his field of view intervened. So he was expecting and he was receptive to whatever instructions I would give him. *G3P6*

Not most of the time, because most of the time, it was me [RH] trying to tell them [LW] what to do. So it was meant to be helpful. *G4P7*

Not at all. In order to accomplish that particular task, it’s very important for an instructor [RH] to see what the worker [LW] is actually doing. So I don’t feel it as interference. It’s actually a good thing. The goal is to accomplish the task, right? So I don’t call it interference, I’m only telling the directions or some do this, do that, to complete the particular thing which was given to us. I would tell you that directions were not interference at any point of time. *G6P12*

Not really, I mean, like, I’ve had to give some instructions like I had to point which blocks to become an order. So I didn’t feel like I was interfering with the work, I felt it was necessary. *G8P15*

From the above quotes, we show that the participants felt that the RH was not “interfering” with the view of the LW. In fact, we never observed a RH ask for permission to draw. Similarly, when we asked participants if they ever asked for permission to draw or erase, their answers were indicative of the action never even crossed their minds.

It [asking permission to draw] did not strike me at all. Yeah, I [RH] think I was just more focused on getting the job done. *G5P9*

The instructor [RH] asking the worker [LW] to draw on their view? No. So we know the instructor knows what needs to be achieved not the worker. The worker just has to do the work. *G7P13*

I feel like the worker [LW] has no say in that. So the instructor [RH] has to state everything and the instructor has to say what to do. So the worker for me, the worker is clueless. So there is no need for an instructor to ask permission. *G8P16*

The fact that the RH was “not interfering” and “didn’t need to ask for permission” would make us assume that the shared view was perceived as either shared ownership or else the RH owned it. This is in contrast to the number of participants who, earlier on, explicitly relayed that they perceived the shared view as being owned by the LWs. Since the justifications we have just shown always had to do with the amount of knowledge and the task’s needs, this suggests that it is related to the task.

To further this point, we also saw that the LW’s never thought to ask the RH’s to remove drawings from the LW’s view. Although we did not provide the LWs the ability to erase drawings from their own view (so they could see better what was underneath or remove directions that were not needed anymore) they had the option at any given time to ask the RH to remove those drawings. Although we did not observe any example of that happening, and participants mentioned in the post-study interview never doing so, this does not necessarily mean that they never wanted drawings to be removed.

Um, I [LW] was thinking it [asking to erase an annotation] at a point I probably should have, like said something. I guess since it was probably helping him [RH] out with leaving some drawings on. So I figured if I’m following that direction, then just to just leave it. *G1P1*

I [LW] never asked him [RH] to erase a drawing ultimately because I know what he’s doing and if he wants to give a new instruction we will know what was the previous one. So let’s say if there was a line here we just for the previous step, we can just ignore it and draw a new one or I also trust him that if he thinks it’s too messy, he will just erase it. *G3P6*

Thus, clearly, participants viewed that it was solely the decision of the RH as to when they would deem it necessary to place an annotation as well as when to remove an annotation. This is a striking finding considering the earlier mixed perception of who owned the shared view within which these annotations overlay. It would be one thing if more of our participants had deemed the shared view as a shared space, but that was not the trend. Instead, the shared view was perceived as that of the LW or, to a lesser extent, the RH owned the space — i.e., a personal space.

On face value, there is evidence here that indicates that both the LW and the RH deemed the shared view as a shared territory. LWs did not erase annotations because the task indicated that if the RH deemed it necessary to leave it there then they accepted it. So, here, the accepted behaviors due to the task itself are what led to shaping what one could do in this particular space as well as what someone should not do.

### 4.3 Interaction Ability Creates Spaces

As the Actionport serves as a mechanism for enabling pointing and annotating the shared view, it seems reasonable to assume it is simply a subspace of the shared view and thus entails the same perceptions of psychological ownership. However, for the most part, the functionality of placing

the Actionport was deemed by participants to be owned by the RH. Again this was most often because of the perceived task needs or the prior experience with doing the task and the needs learned from that (i.e., when the RH had been the LW in the prior session, and so had a good idea of what they needed to be able to see and refer to).

The instructor will be having the idea of where to place the shared workspace right?  
*G6P11*

Well, I sat in the instructor's [RH] seat first. So I knew how I would have wanted it to be aligned. So then, when I was sitting as a worker [LW], I was able to put the green box where I would have wanted it as an instructor. *G2P3*

I think it was from my experience that because I participated as a worker [LW] at first. So I was, I knew that I [RH] needed to, you know, put the box on the table. Just on the table. Experience. *G2P4*

When participants were prompted to think about the action of placing the Actionport from the perspective of being a LW, the participants relayed that they felt unaffected by the placement of the Actionport and thus had no need to be a part of the process.

As a worker [LW], I don't think it really mattered what were the workspace was for, for me as the worker because I could see everything. It didn't really feel necessary for me to ask about the workspace [Actionport] because it didn't really affect what I was seeing. So long as the instructor was able to do their job. *G4P7*

This lack of input from the LW is in contrast to the realization by a number of the participants that the location of the Actionport does in fact have the potential to impact the LW, specifically with regard to the position of the LW's head. In particular, that the natural angle of holding one's head when looking down at the table meant that oftentimes the bottom of the building plate would not be captured by the HoloLens2 video camera.

So I think the first time around, we were both new to our positions. So I think it may not have been clear what I [as RH] could see because I remember to keep having to ask [the LW] to move my field of view down. And also having been a worker, I know that it was uncomfortable to be like this [chin to chest] all the time, I kept wanting to pull my head up. But I knew if I pulled my head up, [the RH] wouldn't be able to see. *G2P3*

Even when a participant recognized that the act of placing the Actionport required the LW's involvement, the participant assuming the role of RH still did not reflect a need to include input from the LW on the location of that placement.

I don't think you can decide where the green thing [feedforward mechanism] goes as the instructor [RH] can you? You just have to wait for the worker to move their head to where it needs to be and then you just click the button to lock it in place. *G2P3*

Essentially, this participant indicated that the RH, and only the RH, is the one to decide when to "lock it in place." This may actually be due to the system design, though, as one participant said the ownership of the shared space was that of the RH because RH has the tool.

I think that was just more oriented towards like, because they [RH] were the one who could fix where they were looking at. *G4P7*

Thus the Actionport is perceived to be owned by the RH. Instead of it being seen as a subsection of the shared view, the Actionport is seen as a separate space along with its own perceptions of ownership and its own norms of behavior.

#### 4.4 Physical Spaces Owned By Those That Interact With Them

The final space we asked about was the physical space for the shared view to capture and the Actionport to be placed on top of for remote interaction. For the most part, the participants perceived the building plate as belonging to the LW because of the RH's lack of functional ability to manipulate anything in the physical realm.

Well, I mean, like, I feel like there's no way for the instructor [RH] to have ownership over the space [building plate & table] if you're not there in a way. So I mean, they would like they can manipulate the shared workspace [shared view] but they can't manipulate the actual [building blocks] platform. So like that just kind of falls on the worker [LW], like, the worker [LW] can manipulate that all they want, and the instructor [RH] can't. So I think that's strictly just for the worker [LW] to control. *G4P8*

I think that was because like, the instructor [RH] can do as much as they want just by telling them what to do with it, but they can't physically be there to manipulate at all so at that point it's the worker's [LW] control and if they wanted to they could move away then you no longer have access to the [building blocks]. *G4P7*

Note that the notion of manipulation in the physical space is highly influencing the notion of ownership for some. This could change if, for instance, remote physical manipulation could be achieved. But, we also had three participants who had a different take on the ownership of the physical spaces. Namely that it was a shared space. And this primarily stemmed from the instructional nature of the task.

Yeah, it's [the building plate & table] the shared workspace. You're both completing the same task. *G2P3*

I'm neutral. Because instructor [RH] might give him the instruction, but if the worker [LW] doesn't put it in their way then it's no ones workspace. *G2P4*

Directions given by the instructor [RH] and the work done by worker [LW]. They're both proportional to each other. *G6P12*

Overall, the participants said the LWs owned the physical space because the RH is not there — i.e., is not able to directly interact with it except through a proxy (the LW). But, the idea of the LW working as a proxy for the RH is also related to the reason why our participants think the physical space is shared — that the RH is controlling the movements of the LW and so the task cannot be done without the RH stating what needs to be done.

## 5 Discussion

Our study investigated how users of teleAR perceived the ownership of virtual and physical spaces and how those users thought their perceptions impacted their interaction within those spaces. We showed that participants do not have a clear agreement on who owns a shared view although they do agree that ownership is not shared. This is surprising as the behaviors around the use of the shared view is akin to group territories — dynamic spaces where collaborative actions take place [20] — as opposed to a personal territory — individual-specific and often requiring explicit permission to access [27]. However, we also showed that the accepted behaviors in the shared view are highly related to the nature of the task — in this case instruction. Thus, we see an acceptance by all participants that a remote helper has full autonomy in when and how they interact over the shared view. This finding is consistent with Lanir et al.'s [19] findings that in instructional tasks in non-AR environments where the helper possesses greater expertise, it is beneficial to give the helper control over the shared workspace view. Our participants seemed to implicitly grant permission to the remote helper, likely due to the instructional nature of the task and the



perceived expertise of the helper. Finally, we showed that although the participants did not agree on who owned the shared view, they did have a clear perspective of who owned the Actionport, which is the mechanism for the remote helper to interact on the shared view. The clear ownership perception of the Actionport is aligned with two studies on psychological ownership of virtual objects in AR environments. Poretski et al. [35] and Carrozzi et al. [8] showed that control over and customization of AR elements can enhance feelings of possession, responsibility, and overall psychological ownership.

In the following two sections, we first posit a layer model of shared AR spaces to explain how the psychological ownership and affiliated normative behaviors on one space can impact the normative behaviors of spaces that overlap it. We then discuss the impact that the nature of the collaborative task has on the amount that one space can impact another.

### 5.1 A Layer Model of Shared AR Spaces as the Basis of Ownership in teleAR

In section 4.3 we showed that the virtual interaction area is perceived as a separate space from the shared view, and in section 4.2 we showed that the RH's interactions in the virtual interaction space are not perceived as "interference" by the LW. In addition, we show in section 4.4 that the physical environment is also seen as a separate space from that of the shared view and virtual interaction area, and that its perception of psychological ownership is not that of the virtual interaction or shared view. To righten these findings with prior work in psychological ownership and territoriality, we post that a layer model of shared AR may clarify why and when normative behavior in one space can permeate between spaces.

Shared AR has been conceptualized as two or more people experiencing and interacting with the same virtual space [3, 39]. We posit that shared AR is constituted of multiple spaces layered on one another. In Figure 4, we detail these layered spaces. The base layer is the physical environment. The space layered over the physical environment is the shared view. Finally, the top layer is the virtual interactions space. This model is not solely for the specificities of the HOLOMENTOR environment. For instance, although HOLOMENTOR explicitly provides a separately named space (Actionport) to support remote helper real-time pointing/annotations, the Virtual Interactions layer would be akin to, say, Microsoft's Remote Assist's snapshot tool that overlays images with telestrations on the shared view. We can also make this parallel with the system *Loki* [50], where the remote instructor uses an avatar to point to the local student's physical space. Our argument is that there are overlapping spaces making up the "shared AR space". In teleAR, these overlapping spaces are the Physical Environment (the real world), the Shared View (the video stream), and the Virtual Interactions (e.g., pointing and annotations). These overlapping spaces will inevitably take different forms in different systems, responding to the specific user and tasks needs for which they are built. HOLOMENTOR is only one example implementation.

The existence of these layered spaces complexifies notions of ownership that differ from those identified in previous work. Poretski et al. [37] observed how possession leads to the feeling of ownership (i.e., *this is mine*) and thus a violation of norms when others edit their virtual augmentations (referred to as intrusion or invasion). In addition, Scott et al. [43] also referred to certain norms of behavior for different territories (i.e., collaborative behavior that is allowed in personal versus shared territories). However, what we see with a layered model is that because the layered spaces overlap, the interactions in one space cross over into the other two spaces. So, when the remote helper draws in the virtual interaction space, the effect of that drawing action is perceived as affecting the shared view and physical environment spaces as well. When the local worker moves the shared view, it changes what the remote helper sees in the shared view as well as what the remote helper can virtually interact upon. Thus, because the outcomes of interactions

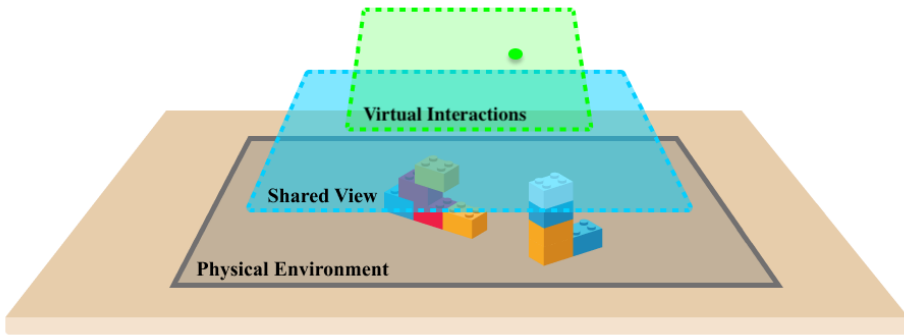


Fig. 4. Layered Model of Shared AR.

cross these layered spaces, the norms of behavior for all three spaces are overlapped and thus affect one another.

Whereas the concept of territoriality has specific accepted behavior for each space and researchers have even talked about spaces overlapping [43], they do not address how the interactions in one space affect the other space. In Shared AR, the accepted behavior in one space can affect all of the other spaces, and so the behavior in one space might then be seen as acceptable in all of the other spaces. This could explain why our participants did not see the remote helper as interfering with the shared view when the remote helper was drawing in the virtual interaction space — even when the participant viewed the shared view as belonging to the local worker. It could also clarify why the local worker did not ask the remote helper to erase a drawing that was in the Actionport although it resulted in occluding the shared view.

However, note that in our study, our task was one of instruction. The participants explicitly referred to the task as the reason for the acceptance of the RH pointing and annotating as they like in the virtual interactions space. The task of instruction is what allowed the norms of behavior in the virtual interaction space — the space perceived to be owned by the RH — to permeate the other spaces that some perceived as being owned by the LW. We may see in future studies that tasks that are more collaborative in nature may have different levels of permeation that are found to be acceptable from one individual's space to another's. In the following section, though, we further explore why and how the task type has this important impact on the behavioral norms of ownership and thus the level of permeation these norms can have across layers.

## 5.2 Instructional Task Impacts on the Behavioral Norms of Ownership

Our study shows that our participants' perceptions of ownership and behavior resulted from the *instructional nature* of the task. The results shed light on instances where the shared space was perceived as owned by the local worker, both, or the remote helper. The shift of perception towards the remote helper is due to their knowledge of the expected end goal, and their responsibility for attaining it. Based on the five dimensions that contribute to the sense of ownership (possession, control, identity, responsibility, and territoriality) [35] we observe that the instructional task shifts ownership from those who *possess* and *control*, to those who are *responsible*.

Previous work studying tasks other than instructional tasks, have shown different notions of ownership. In Carozzi et al.'s work [8] studying how AR holograms shape psychological ownership, the study task involved joint decision-making. The results show that having control (being able

to customize the AR hologram) increased psychological ownership. In Blau & Caspi's [4] study, psychological ownership decreased in a collaborative environment when a peer could edit virtual elements in one's space, and it increased when, instead of editing, the only action the peer could perform was to suggest. The authors provide evidence that the impactful dimension is possession: when learners had to give their writing for editing, they lost possession and thus ownership. Our study, bound to an instructional task, led to different findings, as some participants perceived the remote helper as the owner of the shared view, despite the RH not having direct manipulative control of the physical space, and sometimes perceived the local worker as the owner, although they were not provided any functionality for manipulating the virtual space. Thus, by contrasting our results with previous studies, we see that the type of task influences perceptions of ownership.

We believe that responsibility played an important role in instruction, as the remote helper was ultimately liable for the correctness of the outcome. This shifted in some cases ownership perception towards the remote person. As ownership is the attitudinal state that is associated with team members' feeling toward issues that are worthy of attentional investment [32], we can assume that when the worker does not feel ownership, as in instructional tasks, they will be less invested, and therefore the consequence might be that they perform errors, or, simply execute without other goals, such as learning. The same applies in the other sense, in cases where ownership shifts to the local worker, the remote helper is less invested, and thus might teach less effectively. For instructional tasks that involve learning as a goal, it is thus difficult to decide who should feel ownership. Lanir et al. [19] posit that ownership of gesturing tools, during instructional tasks, should be left to whoever has more knowledge about the task. In their case, this is the local worker, but in our case, it is the remote helper.

Our study also included a particular case where a virtual space (Actionport) required coordinated work during placement. This is the result of working with a *mobile view*, leading to coordination between the local worker (shifts port by looking around) and the remote helper (decides when to stick it onto the real world). Here, both local and remote had *control* over the space, and placing it becomes a collaborative task rather than an instructional task. Still, the remote helper holds the *responsibility*, because this will affect their future work. Carrozzi et al. [8] showed that for a collaborative task, the ability to modify virtual objects (holograms) increased the sense of ownership. What we see in our study is that the sense of responsibility is shifted towards the remote helper, not because they shape the final end result, but because the Actionport placement will affect their future work, shifts also the sense of ownership, even if the local worker also has control.

### 5.3 Areas for Future Work on Psychological Ownership in Shared AR

Further understanding the layered model of Shared AR and how norms of behavior cross between the layers will be an area of future work. For instance, what happens when the norms of interacting in one layer is not accepted as an outcome in a different layer. How, then, do collaborators resolve that incongruence of accepted behaviors. Likewise, evaluating further tasks through remote work, to understand how they lead to different perceptions of ownership and norms of behavior in the various layers must be investigated. For instance, we could start with the concept of "collaborative coupling" [16, 47], which refers to the extent to which collaborators are interdependent. The degree of collaborative coupling could range from being tightly coupled – where interactions are frequent and highly coordinated – to being loosely coupled, which allows for more independent activity. Further research could focus on how the degree of collaborative coupling impacts psychological ownership and territorial behavior within the layers of Shared AR. For example, in a tightly-coupled setting, we might anticipate more disputes over ownership, given the frequent interactions. Conversely, in a loosely-coupled environment, norms around territoriality may be less rigid, given the higher levels of independent work.

Further, the nature of the task itself — be it instructive or cooperative — and the nature of the application domain, play a significant role in shaping psychological ownership. In an instructive task, one worker, often with greater expertise, guides the other, inherently creating a hierarchical relationship based on knowledge. This has its own set of norms and impacts on perceptions of ownership and territoriality. On the other hand, in a cooperative task, workers operate with similar levels of knowledge and in a non-hierarchical manner. This democratic structure leads to entirely different dynamics concerning psychological ownership and acceptable behaviors in Shared AR spaces. Regarding the application domain, there may be constraints that interfere with the behaviors reflecting notions of ownership. For example, in urgent medical care or industrial repairs, the local worker may be more inclined to ask the remote helper to delete annotations if they block their view, not as a result of notions of ownership, but as a result of the critical task. Comparing these forms of collaboration will deepen our understanding of how task semantics influence perceptions of ownership and accepted behaviors in Shared AR.

Further investigation is also needed to understand the implications of enhanced interaction abilities for both local and remote participants, particularly in the context of the “control” dimension of psychological ownership. Providing the remote helper with the option to interact with the shared view (i.e., adjusting the camera’s field of view or manipulating the zoom level) introduces a shared sense of control, which could blur traditional boundaries of ownership and territoriality. This shared control could either foster a more collaborative environment or ignite disputes on norms, over who has the “right” to control specific aspects of the workspace. Similarly, in a case where the remote helper could interact with the physical space via a robotic arm, the ability to physically manipulate objects in the local worker’s environment substantially shifts the control dynamics. This could blur the lines between personal and shared territories, leading to questions of ownership and the acceptable norms of behavior within these newly defined spaces. Furthermore, the local worker’s ability to interact with the Actionport — traditionally under the remote helper’s control — could add another layer of complexity. This redistribution of control could either foster a sense of dual ownership or potentially ignite conflicts over this shared resource. Another line of work involves studying dual-user gesturing tools, where the local worker can also perform actions on the virtual layer where the remote helper acts. This in the past has been shown to improve communication during instructional tasks in shared AR [24], but the study did not look into notions of psychological ownership.

Finally, as new HMD devices are rapidly being released, it is worth studying if perceptions of ownership are influenced by devices with different form factors (for example, optical see-through AR vs. digital pass-through). We recognize that in the study outlined in this paper, the way we framed the interview questions may have suggested individual rather than shared ownership. This is another good consideration for further investigation.

In summary, expanding interaction capabilities is not just a technical add-on; it stands to significantly impact the dynamics of control, and by extension, psychological ownership and territorial behaviors. Future research must take a multidimensional approach to understand these intricate relationships fully.

## 6 Conclusion

In this study, we empirically examined the nuances of psychological ownership in teleinstructive AR workspaces, focusing on the roles of control, responsibility, and task nature. Our findings challenge traditional paradigms of ownership, emphasizing that it is not solely dictated by control or physical presence but is significantly influenced by the instructional nature of the task. First, we have demonstrated that psychological ownership is not unilaterally dictated by control or physical interaction within the workspace. The notion of ownership is significantly influenced by

the instructional nature of the task at hand. Our research also illuminated the role-based dynamics influencing the perception of ownership, especially with virtual spaces like the Actionport. Contrary to expectations, despite shared control, the remote helper was often perceived as the owner. This underscores the intricate interplay of role-based responsibilities and the nature of the instructional task in shaping perceptions of ownership and control. Furthermore, we introduce the concept of “layered ownership” in shared AR spaces, which captures the complex interactions between physical and virtual environments. The Actionport, for example, is perceived as a separate layer, adding another dimension to our understanding of ownership in AR systems. This study offers a nuanced and multi-faceted understanding of psychological ownership in teleinstructional AR workspaces, bridging the gap between physical and virtual ownership perceptions. The study also underscores the need for a nuanced understanding of psychological ownership in teleAR, one that accounts for the interplay of control, responsibility, and task nature.

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**A Post-Interview Guide**

- (1) Why did you place the Actionport where you did?
- (2) Were there any agreements about putting it in that position?
- (3) For when you were in the local worker role, how did you feel about the remote helper drawing or pointing on the view? (Follow-up: Did you feel as if the remote helper is interfering with the view?)
- (4) For when you were the remote helper, how did you feel about drawing or pointing on the view? (Follow-up: Did you feel you were interfering with the view?)
- (5) Who owned the shared view? Why?
- (6) Who owned the Actionport? Why?
- (7) Who owned the building plate? Why?
- (8) Who owned the area outside of the shared view? Why?
- (9) For when you were in the local worker role, did you ever ask the remote helper to erase their drawings? Why/why not?
- (10) For when you were in the remote helper role, did you ever ask the local worker if you could draw or point on the view?
- (11) Which would you like better, real-time drawing, as we provided, or first draw and then share the completed drawing?

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