Field Trial of a Tablet-based AR System for Intergenerational Connections through Remote Reading

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Prior work has explored various technology designs to support intergenerational communications and connections through remote activities such as reading or play. However, few works have explored these technologies outside the family settings. In this work, we aimed to understand how technology can support social connectedness through remote activities, by investigating the use of a tablet-based AR system among older adult volunteers and students for remote reading. We developed the system based on insights from previous research, deployed the system in the field, and observed the use of the system over six months. With the data collected from the field, we present a rich description on the use of the system and the practices that emerged around its usage in a real-world setting. Our findings highlight the importance of supporting an engaging reading experience and context understanding for social connections with the technology design. We provide insights into how such technology can support intergenerational communication and foster social connectedness.

CCS Concepts: • **Human-centered computing → Empirical studies in collaborative and social computing**.

Additional Key Words and Phrases: intergenerational communication, social connection, children, older adults, remote reading

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1 INTRODUCTION

Reading activities play a significant role in nurturing relationships between intergenerational family members, such as between grandparents and grandchildren, as well as between parents and children [71, 89]. For intergenerational family members, reading stories together can provide a shared context for communication, especially during videochat facilitated remote communication, and provide more opportunities for bonding between generations. Communities in the United States also leverage intergenerational reading activities for multiple purposes, including improving student learning, empowering older adults, and fostering community growth and resilience [91].

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Programs like *Experience Corps*[1] by AARP Foundation connect older adults with students in their local elementary schools to enhance their reading skills. These programs can provide opportunities for older individuals to share their knowledge and experience with younger generations, hence building a sense of belonging and strengthening the connections in communities.

However, these community programs face constraints due to logistical and organizational challenges. Older adult volunteers are required to commute to school sites for in-person participation, which can be hindered by health-related conditions. The recent COVID-19 pandemic further exacerbated this issue. When in-person gatherings and activities were restricted in most public spaces, many of these community programs were interrupted. Losing access to these programs reduced opportunities for social connections and resulted in increased isolation in communities. As many activities have started supporting remote formats during the pandemic (e.g., remote learning in schools), there are opportunities for technology to help expand access to these valuable community resources through supporting remote formats of these intergenerational activities. With the expanded access, these programs can also benefit vulnerable older adults and children who cannot easily meet in person, and offer support during the time of isolation caused by personal health problems (e.g., limited mobility when recovering from injury). While prior research has explored various technology designs for remote activities in family settings, questions still remain about how the previous insights can be translated to different relationship contexts. To understand opportunities for technology to better support intergenerational connections in a community setting, we designed and developed a tablet-based Augmented Reality (AR) system for intergenerational remote reading. With the support of our community partners, we deployed the system in two elementary schools and four older adult volunteers' homes. Our system allowed both parties to engage in reading sessions beyond merely viewing the book through the video, enabling interactions using their environmental objects and hand gestures. We planned our field deployment study to understand three specific research questions:

- (RQ1) How is the system used by volunteers and students during the deployment?
- (RQ2) What reading practices emerge around the use of such an AR-based system by volunteers and students?
- (RQ3) What social practices emerge around the use of such an AR-based system by volunteers and students?

In the following sections, we begin with an overview of related work in technology-supported intergenerational connections. We then describe our system design, and the details of our deployment study, including the context and settings, study procedure, recruited participants, and analysis process. We present findings and implications from our analysis. With the system design and the field deployment study, we contribute an empirical understanding of the real-world usage with a tablet-based AR system, the needs of users in real contexts, and opportunities to improve technology designs for intergenerational connections in community settings.

2 RELATED WORK

2.1 Technologies for Intergenerational Social Connectedness

Supporting intergenerational communication among family members can facilitate mutual learning and understanding among individuals of varying ages [87]. It can help build and strengthen the bonds within the family, as well as improve family's overall health and well-being [7]. Two main forms of intergenerational connections have been investigated in HCI and Social Computing related research: between parents and children (e.g., [7, 31, 71]), and between grandparents and children (e.g., [9, 80]).

[1]AARP Foundation Experience Corps: https://www.aarp.org/experience-corps/

Communication and activities in both in-person and remote settings can foster intergenerational connections. Researchers have explored technologies to support various activities in co-located setting, such as playing physical and digital games [64, 74, 76, 77], or organizing family routines [1, 14, 35]. These activities provide an opportunity for all members to spend quality time together and engage in meaningful conversation exchanges. Alternatively, technology-facilitated remote communication, including videochat, social media, and text messages, allows children and their loved ones to chat and connect over a distance [16, 75]. Prior research has also explored novel technology systems to support informal learning [71], remote presence [48, 89], and awareness [64, 73] in family settings.

Outside the family context, interactions between children and adults are also beneficial for their participants. These interactions can provide guidance and support for the development of children [66]. Likewise, adults can benefit from such interactions by staying connected with younger generations to better understand the issues and concerns that are important to these generations [39]. More importantly, intergenerational communication can reduce older adults' feelings of loneliness [18]. Prior work has investigated how technologies can provide support for mentoring activities in education context, such as providing virtual or robot agents as tutors in learning math [51], science [83], language [84], and computer science [34]. However, when compared to these agents, humans—especially in face-to-face settings [33]—were more skilled at detecting social cues and adapting socially when interacting with children, leading to better academic results [50].

Many intergenerational technology systems support and encourage shared activities during remote communication, given the benefits of better engagement with children compared to traditional videochat-based communication [2, 81]. Remote storytelling is one example of such activities that can maintain children's interests [26] during videochat-based remote communication, which often involves sharing stories and experiences with one another for connections (e.g. [71, 80]). Besides, remote play, like online games, can also provide contexts and opportunities for different generations to engage and connect over distance. Researchers have investigated systems like *Video Play* [27] and *ShareTable* [89] for supporting intergenerational shared activities like playing games over video streaming. Inspired by these prior works, our study focuses on supporting intergenerational connection in a community setting, through shared activities that follow existing reading practices within the community. With the system prototype and the deployment study, our work examines the social aspects and the outcome of technology-mediated reading activities.

2.2 Technologies for Collaborative Reading

The HCI community has taken advantage of digital platforms (e.g., [41, 82]) and investigated a variety of digital tools to support existing reading practices, such as supporting annotations (e.g., [15, 43]) and inking (e.g., [68]), in collaborative settings. Digital reading (e.g., e-readers and tablets) has become increasingly popular in recent years, since it allows individuals to access a wide variety of texts and interact with others via the reading platform. Annotation is one of the important reading-related practices that researchers have aimed to support, since it allows readers to highlight important text, make notes for later reference, and share thoughts with others. Many studies [65, 67, 72] have demonstrated that collaborative annotation tools can improve reading performance and benefit collaborative reading. Inking is another important reading-related practice that involves the use of digital pens or styluses to write or draw on a digital device. Inking can be particularly useful for remote communication and collaboration, as it allows individuals to share and collaborate on text-based content in real-time with handwritten notes and drawings [57].

Previous studies have investigated different types of reading-related technologies in both in-person and remote collaborative setups. For co-located settings, Xu and Warschauer [88] explored the usage of a conversational agent as an in-person reading partner, investigating patterns of children's conversation and interactions during the reading. The results showed that effective joint reading between children and the agent can increase children's learning and engagement. Another system, *Mobile Stories* [24], empowered co-located children to collaboratively read and create stories through specific role assignments.

To support reading activities over a distance, *Family Story Play* [71] combined a videochat application, an interface with a physical book, and a virtual character as a guide and a listener in the system design, to improve the storytelling experiences between children and grandparents. *Story Box* [80] is another storytelling system designed for grandparent-grandchild relationships, enabling them to share daily stories by placing objects in a physical box. This system also allowed users to create digital ink and audio annotations to exchange information with physical objects. In addition, media space systems can support remote reading as a part of the collaborative activities they facilitate (e.g., *ShareTable* [89]), which we provide more details in the following section 2.3. Our system design emphasizes supporting existing reading experiences and practices (i.e., enabling tangible interactions, the usage of physical books and objects through AR) in a remote setting. With the long-term deployment study, we wanted to investigate the specific design and its usage in a real-world context.

2.3 Technologies for Remote Collaborative Workspace

Researchers have studied media spaces in the workplace for over three decades to maintain social and work connections between distributed collaborators [12]. Videochat apps (e.g., [5, 6, 11]), messaging and group chat tools (e.g., *Slack*, *Discord*) have been commonly investigated for constructing a shared workspace for remote collaborative work. In addition, Virtual Reality (VR) [62, 69, 78] and AR tools [22, 25, 38, 58] have been explored in system design, given their potentials in creating immersive and interactive experiences, which can enhance collaboration and creativity. For example, tools like *Microsoft Mesh* [2] and *Meta Horizon Workrooms* [3] enabled the usage of personalized avatars and virtual meeting spaces for distributed teams on PCs, mobile, and VR/AR headsets, which support adding 3D space information to task sharing and team working.

Media spaces also have been investigated as an approach to promote communications and awareness in the social context. The shared visual spaces in media spaces often provide a shared view of the work area as well as one of all the collaborators [47]. Sharing views of the workspace can increase participants' performance and enable effective communication by helping collaborators understand the current task state [20, 32, 47]. The shared view of the collaborators can convey detailed social cues including gestures, posture, and facial expressions in remote collaborative work. Both views contribute to the effectiveness of collaboration and communication over a distance.

Many collaborative spaces (e.g., [40, 49, 60, 89]) can be used for a diverse range of activities, including facilitating specific activity instances (e.g., reading, playing, writing), as well as extending or supplementing existing activities (e.g., promoting social awareness in remote work). For example, *ShareTable* [89] allowed child-initiated videochat through a shared tabletop system, where geographically distributed family members can share emotional moments and objects, provide instrumental care, and participate in other playful activities. *Family Portals* [63] is an always-on system that provides a continuous video connection for sharing everyday life and promoting awareness between families. Unlike *ShareTable*, this system focuses on asynchronous interaction—annotating messages on top of the video feed. *ThingShare* [40] is another example of a videochat-based system designed to facilitate the sharing of physical objects, where users can create digital copies of physical objects and integrate them into their video feeds. These system examples from prior work all incorporated

[2]Microsoft Mesh: https://www.microsoft.com/en-us/mesh
[3]Meta Horizon Workrooms: https://www.meta.com/work/workrooms/

AR components (e.g., physical objects, gesture annotations) into their video streaming setups to enhance awareness and engagement during remote communications. We drew inspiration from this body of literature on system designs for collaborative media spaces, and explored the media space system design that supports remote collaborative reading and social connections. Our findings from the system's field usage provide insights into design implications for collaborative technology and can be extended to a community-based social setting.

3 SYSTEM DESIGN AND USAGE

3.1 Design Rationale

The design of our system was inspired by prior research in technology-mediated intergenerational communication (e.g., [30, 71]), technology design for social connectedness (e.g., [1, 27, 28, 74, 89]), and technology supported collaborative workspace (e.g., [10, 24, 71, 90]). There are three specific goals we aimed to address in our system design: 1) supporting intergenerational connections through shared activities (e.g., [26, 30, 71]), 2) supporting tangible interactions for an engaging activity experience (e.g., [4, 29, 80]), and 3) supporting rich communications for social connection opportunities (e.g., [45, 79, 89, 91]). Previous work has highlighted some popular intergenerational activities that technology can support for social connections, such as reading [29, 71], storytelling [23, 80], and game play [36, 53, 56]. While we prioritized supporting remote reading in our system design, based on the current community practices and programs for intergenerational connections (e.g., reading tutoring programs), we also considered the ability to support other common activities such as puzzle play when designing our system.

We viewed our system as a technology probe—a functional, simple, and flexible prototype aiming to collect information about the usage of the desired functionality, the feasibility of the technology, and the needs of the users in a real-world setting [42]. With this consideration in mind, we wanted to design a field-deployable prototype, allowing a long-term study that participants can manage independently without help from researchers. Therefore, considering the emphasis on simplicity and flexibility in our system prototype, we decided to incorporate both custom and commercial products to prototype our system design. Even though we iterated and thoroughly tested the system beforehand, our system design aligns more closely with the technology probe approach.

We arrived at an AR approach for tangible interactions in a tablet-based system for three reasons regarding supporting remote intergenerational reading and social connections. First, AR has been widely adopted in learning and education-related settings to increase users' attention and improve their interests [44, 70], which can improve participants' activity and social experience and the related outcomes. Second, prior work suggested AR systems can support child users' complex cognitive and social development needs in early childhood [17]. Third, AR can reduce the perceptual constraints by increasing the match in visual characteristics between the digital media and the real-world object perceived by children, as the potential mismatch of visual cues can place considerable cognitive demands on a memory system that is not well developed for children yet [37]. In the following section, we provide a detailed description of system components, implementation, and its intended usage.

3.2 System Components and Implementations

Our AR-based system consists of a physical stand and two tablets with different applications loaded on each tablet. The **physical stand** (Fig. 1(4)) constructs **a task space** (Fig.1(3)) for users to share physical and gesture interactions. The colored mat (Fig. 1(3)) provides a colored surface for constructing gestures shared in the space: a dark-colored mat and a light-colored mat for sharing gestures and objects in different usages. Two different slots (Fig. 1(1)(2)) are designed for two tablets

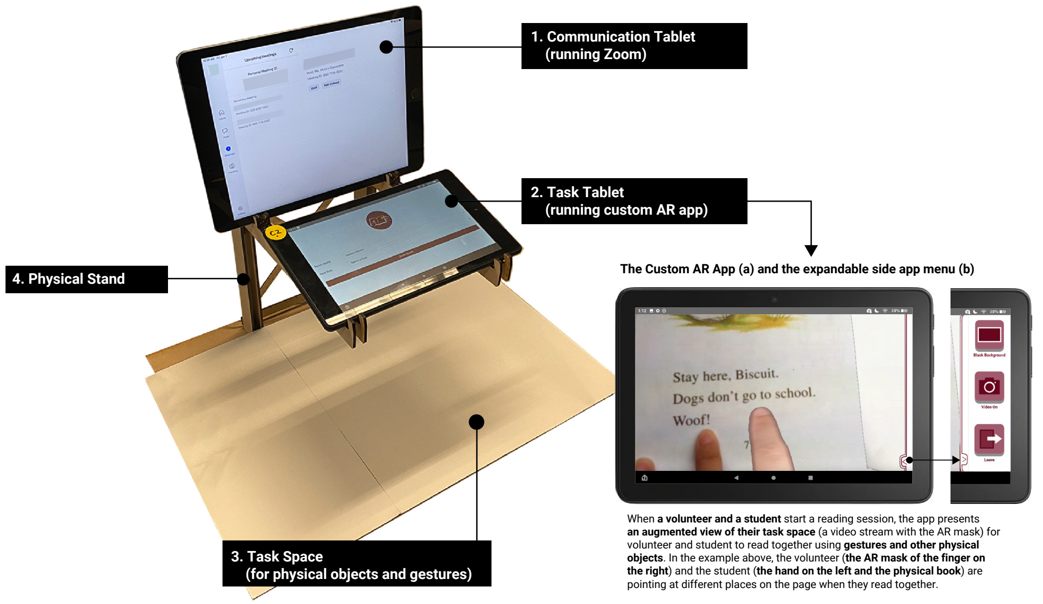

Fig. 1. Our tablet-based AR system includes 1. a tablet running Zoom dedicated to video and audio communication, 2. a tablet running our custom AR app dedicated to a shared reading experience, 3. a task space for users to place physical objects and gestures, and 4. a custom physical stand that holds both tablets and carves out a task space. 2 (a&b) provides an example of the custom AR app during a reading session. The main view of the app is an augmented view of the user's shared task space with an AR mask.

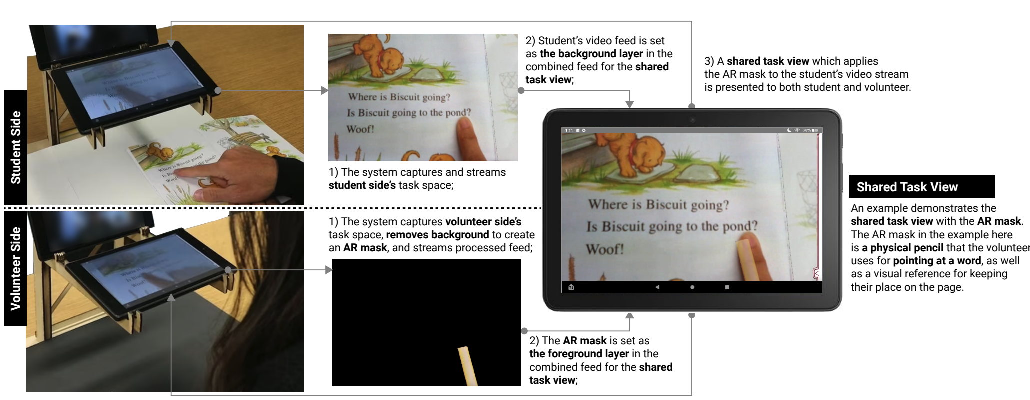

Fig. 2. Detailed flow demonstrates the video processing behind our custom AR app: 1) the camera on the task tablet captures and streams the individual task space, 2) then based on the role of the participant (volunteer or student), our app either removes the background of the captured video feed to create an AR mask (volunteer side) or streams the captured video feed (student side), and 3) our app combines the AR mask with the video feed for a shared and augmented task view.

used for shared task space and personal space during remote communication. The physical stand is self-designed and constructed using laser-cut wood board.

The **task tablet** (Fig. 1(2)) uses the environment camera to capture objects and gestures shared in the task space. This tablet loads **a custom AR-based video app** that generates **an augmented view**, establishing a shared space for activity performance. This augmented view is generated by capturing and processing the task space from both student side (who aim to share physical materials) and volunteer side (who seek to interact with materials using gestures or other objects), then merging them into one shared view. The foundational elements of this view are derived from the video feed of physical content on the student side (whose role will be identified when they join a session). From the side of volunteers (who self-identified their roles before joining a session), objects and gestures are extracted from the background as an AR mask. This AR mask is overlapped (i.e., "augmented") with the view from the student side, allowing volunteers to view and interact with the physical objects shared by students. The application is developed on the Android operating system (Java-based app framework with web app components using JavaScript) and it incorporates the WebRTC framework [4] to stream and synchronize the real-time augmented video streams. For creating the AR mask from the captured video stream, we used pixel-wise background removal techniques to process the video feed from the volunteer side (i.e., process each frame of the video stream to remove the pixels for the background). Figure 2 summarizes this process for generating an augmented share task view. We also provide more details about the app usage in section 3.3.

The **communication tablet** (Fig. 1(1)) uses the face camera to capture users' faces and voices to facilitate communications between users. This tablet is used to load the commercial videochat application for video and audio communication, such as *Zoom* in our work, which also helps create **awareness** and **a sense of togetherness** during shared activities.

3.3 Intended System Usage

To start a remote activity and reading session, users first place the communication tablet on the stand and join the videochat (i.e., *Zoom*) session with their activity partner. Setting up the communication tablet first allows users to see and greet each other as well as coordinating over the activity when they are ready to set up the task tablet. Then, users place the task tablet on the stand and launch our custom AR-based video app. Both users need to select the same room from the landing page to join the same activity session. The landing page has two dropdown boxes for selecting the activity room and the user role, and a button for starting/entering the session. For users who intend to share physical content and objects, they need to select their role as **student**. For users who want to view the shared content and interact with gestures or other objects (e.g., using hand gestures in Figure 1(a), or pencils in Figure 2), they need to select their role as **volunteer**. Volunteer's interaction will be displayed as an AR mask overlapped with the student's task space shown in the task tablet. We also designed a researcher role considering the needs for field deployment, who will only be able to observe the activity session. Once users tap on enter room, they will join the shared task space for the remote session (Fig. 1 2(a)). There is a side menu in the app (Fig. 1 2(b)), which can be expanded by tapping on the side arrow. The menu provided options for changing the background mat color (which adjust to different skin colors for better outcomes with background subtraction), toggling the front and back camera, and leaving the current activity session.

4 FIELD STUDY

In this section, we describe the background and context for our study, the procedure, demographic information about our participants, and our data collection and analysis process.

[4]WebRTC, a real-time multimedia communication framework: https://webrtc.org/

4.1 Background and Context

For our system's deployment, we wanted to leverage the current community's practices, instead of starting from scratch. We built a partnership with a volunteering program in a metropolitan area in the Upper Midwestern United States, which connects older adult volunteers and young students in the community. The program pairs up volunteers with local schools (mostly elementary schools) where volunteers regularly visit in person during the school year to help students with reading, or other academic subjects. Through this program, older adult volunteers can contribute to their local community and build strong connections with others. However, this volunteering program was heavily interrupted by the recent COVID-19 pandemic, when in-person activities were prohibited or restricted in most public places. This interruption affected each volunteer differently: some volunteers were able to continue the volunteering activities through remote technologies used in the classroom (e.g., *Zoom*, *Google Meet*), while some volunteers had to stop the volunteering activities completely. While most school districts in the area were still navigating their post-COVID policies towards in-person volunteers in the schools, we hoped that our study could also help expand access to these resources for older adults and children during this time.

The current volunteering program requires many efforts from the teacher and the school, to facilitate the activities for volunteers and students on site. Thus, we partnered with two teachers from local elementary schools in the same area, who had prior experiences working with both children and older adult volunteers from the program. Teachers often help communicate the latest school schedule to volunteers, assign specific students to work with volunteers, and decide tasks (e.g., books, worksheets) they need to work on. We involved teachers as research partners in the study preparation phase, to make sure that we considered facilitators' perspectives when planning.

To plan the study, we conducted two preparation workshops with our research partners in the summer of 2021. Each workshop lasted for about 90 minutes, with different emphases: the first workshop focused on presenting the current system prototype, and collecting feedback on system design from our research partners. The results were used to improve and refine the system design (section 3); the second workshop focused on discussing the study plan and logistics, as well as recruiting strategies. The results helped us to recruit participants and make sure the study design and logistics were well-organized and efficient. By the time we started our deployment study (November 2021), the local elementary schools that our research partners associated with still had face coverings or masks mandate as part of their COVID-19 protocols, which requires all staff, students, and visitors to wear a mask on school sites. The schools also just started slowly resuming in-person visitor-related activities (e.g., on-site parent and community volunteer activities) after the restricted visitor policy during the pandemic. The mask mandate was later lifted (i.e., staff and students can choose to wear a mask based on their preferences or level of risk) towards the end of the deployment study (March 2022).

4.2 Procedure

The deployment study took place in the schools during regular school hours. Volunteer participants joined these individual sessions from their homes. We had the systems deployed at two local elementary schools that our research partners are associated with, with one system deployed in the school's library space, and one deployed in the hallway outside the classroom (Figure 3). For volunteer participants, our systems are deployed in their houses, and the specific space is decided based on their preferences (Figure 4). Each volunteer participant was paired with two students and one teacher (our research partner), and they interacted with each other on a weekly basis. Although our partnered volunteering program covers a diverse range of activities such as reading, writing, and counting, we focused on supporting reading activities (volunteers and students read books together) with our system.

Fig. 3. Pictures of students' system setup at schools, in the hallway outside the classroom (left), and in the library (right).

Fig. 4. Pictures of all volunteers' setup of the system at home, including living rooms, hallways, home office, and bedroom (from left to right).

4.2.1 Recruitment. With the connections formed with the local volunteering program and the school district, we recruited our participants through our research partners. For recruiting volunteer participants, we had the volunteering program forward an information flyer to their older adult volunteers. We then followed up with detailed study information with volunteers who were interested in participating in the study. We decided to recruit older adult volunteers who have experience working with students since new volunteers were occupied with learning how to work with students. For recruiting students, we had the teachers identify potential student participants from their second-grade classes and reach out to their parents to communicate their children's participation in this study. Then, we either followed up with parents directly to complete the parental consent forms or had students take the forms home for parental consent.

4.2.2 Onboarding Session. The onboarding sessions with volunteer participants were conducted in person. Each session lasted for about an hour, including the consent process, completing the demographic and background questionnaires, the questionnaire on the sense of belonging with their communities [59], a 15-minute interview, and a 45-minute technology training session. These onboarding sessions were audio recorded.

Following the onboarding sessions, we scheduled a 30-minute dry run with each volunteer participant to walk them through a regular reading session remotely, with researchers playing the role of students. We held these dry run sessions to help volunteer participants build confidence in using our system to read with students. After the dry run sessions, we had a pilot session scheduled for each volunteer-student pair. During these pilot sessions, one researcher was present in person at schools with students, to give student participants a brief technology training at the beginning of the pilot session, and provide technical support. One researcher was also present remotely through videochat, to provide the necessary help.

4.3 Deployment Study

We deployed the system for at least eight weeks and at least eight sessions for each volunteer-student pair. The actual deployment started in November 2021 and ended in April 2022 (six months), because of changes in school schedules (e.g., school cancellation due to severe weather) and students' absences. Each week, a volunteer participant met with two students separately to read one to two books together (about 15-20 minutes). Depending on teachers' different preferences in scheduling these sessions, the volunteer participant either met with two students on the same day during a one-hour block, or met with students on different days during a 30-minute block.

With the *Zoom* videochat application, we video recorded all reading sessions in order to analyze the interactions and behaviors of the volunteer participants and students during the reading sessions. We joined remotely during these reading sessions, to observe the activities and provide necessary technical support. We turned off the camera and microphone to minimize our presence, and unmuted ourselves only when participants asked for help.

In addition to the data collected during the regular reading sessions, we also collected information about students' motivation in reading using the reading motivation questionnaire [86] and their sense of closeness with their reading partner using the closeness questionnaire [3]. We collected this information at the beginning of the deployment (during the first week of the study), and at the end of the deployment (during the eighth week).

To gather ongoing reflections during the study, we checked in with volunteer participants weekly through phone calls. We also checked in with teachers every other week, to collect reflections from the classroom's side. Since we are following the Action Research approach [61], these ongoing reflections with participants and research partners allowed us to adjust our study to improve participants' experience.

4.3.1 Debriefing Session. At the conclusion of each participant's deployment period, we conducted semi-structured interviews with volunteer participants about their experience using the system, perceptions of their connections with their reading partners, and feedback for system design. Each debriefing interview with a volunteer lasted about one hour. We also had short debriefing sessions and questions with our student participants, which were conducted either in-person or remotely, to collect their feedback and preferences towards the technology. We conducted a 30-minute debriefing session with teachers as well, to understand their facilitation effort and their input towards the technology design.

4.4 Participants

A total of four older adult volunteers (three female and one male volunteers, average age = 79.5 years old) and eight second-grade students (five female and three male students) were recruited for the study. We compensated volunteer participants with a 15 US dollar gift card for completing the onboarding process, a 45 US dollar gift card for completing the entire deployment study, and a 15 US

Table 1. Overview of teachers, volunteers, and students information, including gender, age (volunteers and students), and years of teaching experience (teacher).

School	Teacher (gender, grade, years of teaching)	Student (gender, age)	Volunteer (gender, age)
SC1	T1 (F, 2nd Grade, 5)	S1 (M, 7)	V1 (F, 82)
		S2 (F, 8)	
		S3 (F, 8)	V2 (F, 88)
		S4 (F, 7)	
SC2	T2 (F, Interventionist, 33)	S5 (M, 7)	V3 (M, 78)
		S6 (M, 8)	
		S7 (F, 8)	V4 (F, 70)
		S8 (F, 8)	

dollar gift card for completing the debriefing interviews. For student participants, we compensated them with the gift of their choice with the value of 20 US dollars at the end of the study.

Our volunteer participants had 7.75 years of experience on average with the volunteering program that involves interactions with younger generations (SD = 9.14). Although one of the volunteers had just started this volunteering program reading with elementary school students, she had many years of experience working with younger generations (e.g., middle school and high school children) through other local volunteering programs. Table 1 provides detailed information about our participants' information. All of our volunteer participants had experiences with basic communication technologies such as smartphones and laptops or desktops, as well as prior experiences with various videochat applications (e.g., *Zoom*, *Google Meet*, *Facetime*). Some of our volunteer participants were more tech-savvy. They used wearable devices (e.g., *Apple Watch*) and smart home devices (e.g., *Alexa*, *Google Nest*). V1 was also very confident when talking about her technology experiences, and referred to herself as "*a Zoom expert*" when we asked about her previous experience with videochat apps. All of our student participants had their own *iPads* at school, where they used various learning and reading apps on their devices.

4.5 Analysis

For all the audio recordings of debriefing sessions, we transcribed recordings to convert them to textual format. We then analyzed these data together with field notes following a reflexive thematic analysis [13] to generate insights. With the recordings of the regular reading sessions, we coded these recordings for basic session information (e.g., session length, reading time), technical challenges (yes or no), whether student and volunteer greet and say goodbye to each other, and number of personal conversation exchanges in this reading session. We used this information to provide concrete examples to answer *RQ1* and supplement the insights generated from thematic analysis. We also analyzed the measurements collected on participants' sense of closeness with each other and volunteer participants' sense of belonging with their community to understand the changes in their sense of connectedness with their reading partners and their communities

(*RQ3*), the measurements collected on student participants' reading motivations to understand the changes in their motivations for reading (*RQ2*). These measurements were analyzed by looking at the differences between averaged responses.

5 FINDINGS

In this section, we first report the general system usage by volunteers and students from the deployment study (*RQ1*), as well as the challenges and considerations for system deployment beyond this study. Then, we present findings on interactions and practices emerged from remotely reading with AR enabled tangible interactions (*RQ2*). We also present insights on social practices emerged between volunteers and students around the usage of our system prototype (*RQ3*).

5.1 How is the system used by volunteers and students during the deployment (RQ1)?

5.1.1 Summary of General System Usage by Volunteers and Students. Across the six-month field deployment study, the four volunteer participants and eight student participants completed a total of 71 reading sessions (including the pilot reading sessions) using our system. Each volunteer-student dyad completed at least eight reading sessions, and the average session duration was 23.2 minutes (*SD* = 10.28 minutes). During each remote reading session, student participants read 1.95 (*SD* = 1.92) books on average. We report general system usage in this section, including the setup process, technology breakdowns, and challenges. We report more findings on participants' system usage related to the AR aspect of the design in sections 5.2 and 5.3.

Volunteer participants set up the system in various places in their homes: home office, bedroom, and living room (Figure 4). Volunteer participants often set up our system 10 to 15 minutes before the scheduled remote reading session, such as moving the system to the part of the living room with better lighting, turning on the tablet, and logging in on the apps. Both V2 and V4 spent extra time at the beginning of the deployment (e.g., 30 minutes before the scheduled remote reading time) setting up the system because of their stress and anxiety with managing technologies that they were not familiar with. Despite the extra effort in setting up, all volunteers were able to use our system to read with students and engage them in the reading through gestures and conversations. As V4 commented, she felt really engaged and focused during the remote reading session facilitated by our system, and felt "*just a student and me*."

Student participants used the system at different locations in two schools: S1-4 joined the reading session from a table in the hallway outside their classroom, and S5-8 joined the sessions from their school's library (Figure 3). Both teachers facilitated the system setup process, including placing tablets on the stand, and launching the applications (*Zoom* and our custom AR app). Once the system was set up properly, teachers would get the student participants to start the remote reading session. Student participants needed to focus on placing the books in their task space and sharing the content properly with volunteers when reading. Some students may be prompted by our researchers or volunteers when troubleshooting some technical issues or turning off the system properly when the remote reading session ends.

5.1.2 Technology Breakdowns during the Deployment Study. Thirty out of the 71 remote reading sessions had some technology issues with the system, and we were able to help resolve most of them quickly or suggest an alternative setup to continue the reading without disrupting the session. Only one session between V2 and S3 was canceled and rescheduled because of issues with V2's internet connection and bandwidth. During three of V2's sessions, her task tablet lost WiFi connection after setting up her communication tablet, and we had to prompt the student to use the communication tablet to show V2 the reading content (by positioning the book in front of the communication tablet's face camera to show the picture after finishing reading the current page). V4 also had two major technical issues during the study when reading with S7 and S8. We prioritized reading over fixing the system and prompted participants to use the one-tablet configuration to share the book and complete the reading session. Other technical issues mostly involved audio quality and connections (13 sessions), and viewing the shared task view in our custom app on the task tablet (5 sessions), which we often were able to resolve by prompting volunteers to toggle the microphone, or temporarily leave and rejoin the session. During the debriefings, our teacher and volunteer participants talked about the importance of having researchers as technology support during the reading sessions throughout the study, which helped reduce volunteers' stress during technology breakdowns, as well as alleviating the burden of technology facilitation from teachers (who are often considered responsible in similar scenarios).

5.1.3 Challenges and Considerations for Deployment Beyond the Study. During the debriefing sessions, our participants discussed potential challenges and considerations for deploying our system beyond this study, based on their experience using the system throughout the study. The main physical restriction mentioned by V1, V2, and V4 is the height of the stand. For a better viewing angle from a comfortable sitting position using our system, it required our stand to be placed on a lower desk or used with a higher stool, and sometimes our participants needed to stand while using the system (both volunteers and students). Given the relatively short duration of the reading session, most volunteer participants mentioned the height of the system stand was not a problem for them to continue these reading sessions, but might be a challenge for future usage. Our tablet-based system functioned without external power, but both teachers preferred connecting it to power sources to reduce management efforts amid their busy regular class schedule.

Our participants also valued the portability of our system, and discussed potential usage of the system if it could be even more portable. Working with lower grades in an elementary school, T1 mentioned the benefits of being able to store the stand and the tablets in a more secure and less busy space inside her classroom, and only took it out when needed to prepare for the reading session. V4 also commented on the ease of moving the stand around for her remote reading setup. She further commented that if the stand could be more portable and easier to carry for a trip, she could continue the reading session when she is on vacation during the winter time. Both S1 and S4 mentioned that they would like to use the system to read with volunteers or others from home, but S4 mentioned that if they want to do so, they would need to be able to carry the stand when riding the school bus home.

5.2 What reading practices emerge around the use of such an AR-based system by volunteers and students (RQ2)?

We asked the students to fill out a reading motivation questionnaire to investigate the effect of our intervention, during the first week of the deployment, and after they completed all remote reading sessions. Table 2 provides an overview of student participants' responses to the reading motivation questionnaire. Most changes we observed regarding students' reading motivations are small, which are less than or equal to 0.25 Likert scale. Only one change greater than 0.5 Likert scale (Table 2 Q6) suggests students are more motivated to share good books they read with their friends after reading with volunteer remotely. The average score for most questions in the first week (14 out of 20) is above 3, suggesting that our student participants might already have high motivations for reading before they started the deployment study.

Although most of the students' responses regarding their reading motivations had very small changes after the intervention, most students answered maybe (5) or yes (2) when we asked if they would like to use our system to read again with a remote volunteer. Six out of eight students ranked our system as the most fun for reading (while the other two student participants ranked our system as the second most fun), compared to in-person reading and regular remote reading (e.g., just via *Zoom*).

During these reading sessions, we observed reading practices and interactions that were similar to those when reading in person (i.e., following our system design goals in supporting in-person reading practices), as well as new ones emerged from using an AR-based system for remote reading with gestures and physical objects. We discuss these insights in this section related to our second research question.

Table 2. Changes in reading motivations responses from students. For each question, we calculated the average of the responses and reported the standard deviation. The changes are color-coded, with green for positive changes and orange for negative changes.

(on a 1-4 scale)	**Week 1**	**Week 8**	**Changes**
Q1. My friends think I am (a poor reader - a very good reader)	3.38 (0.74)	3.38 (0.74)	0
Q2. Reading a book is something I like to do (never - often)	3.63 (0.52)	3.5 (0.53)	-0.13
Q3. When I come to a word I don't know, I can (never figure it out - almost always figure it out)	3.25 (0.71)	3.63 (0.74)	0.38
Q4. My friends think reading is (no fun at all - really fun)	3.13 (0.64)	2.75 (0.89)	-0.38
Q5. I read (not as well as my friends - a lot better than my friends)	2.5 (0.76)	2.75 (0.89)	0.25
Q6. I tell my friends about good books I read (I never do this - I do this a lot)	1.88 (0.83)	2.5 (1.2)	0.63
Q7. When I am reading by myself, I understand (none of what I read - everything I read)	3.13 (0.35)	3.13 (0.64)	0
Q8. People who read a lot are (very boring - very interesting)	3 (0.53)	3.13 (0.64)	0.13
Q9. I am (a poor reader - a very good reader)	3.13 (0.83)	3.38 (0.74)	0.25
Q10. I think libraries are (a really boring - really great place to spend time)	3.75 (0.46)	3.5 (0.53)	-0.25
Q11. I worry about what other kids think about my reading (a lot - never)	3.25 (0.89)	3.5 (1.07)	0.25
Q12. I think becoming a good reader is (not very important - very important)	3.88 (0.35)	4 (0)	0.13
Q13. When my teacher asks me a question about what I have read, (I can never - always think of an answer)	3.25 (0.71)	3.13 (0.64)	-0.13
Q14. I think spending time reading is (really boring - really great)	3.38 (0.52)	3.63 (0.52)	0.25
Q15. Reading is (very hard for me - very easy for me)	3 (0.53)	3.38 (0.52)	0.38
Q16. When my teacher reads books out loud, I think it is (really boring - really great)	3.63 (0.74)	3.5 (0.53)	-0.13
Q17. When I am in group talking about books I have read (I hate - love to talk about my ideas)	3.13 (0.83)	2.75 (0.71)	-0.38
Q18. When I have free time, I spend (none of my time - a lot of my time reading)	2.5 (1.07)	2.63 (0.92)	0.13
Q19. When I read out loud, I am a (poor reader - very good reader)	2.88 (0.83)	3 (0.76)	0.13
Q20. When someone gives me a book for a present, (I am very unhappy - very happy)	3.13 (0.35)	3.38 (0.52)	0.25

5.2.1 Interactions and Engagement with Reading Content in the System. Volunteers and students used gestures and verbal communication to engage with the reading content during the remote reading sessions, which is similar to in-person reading practices and interactions. Students often pointed at the content when reading and sharing their physical books in their task space with volunteers, while volunteers often utilized the AR mask to interact with the shared physical reading content with hand gestures or other physical objects. At least four student participants (S3, S6, S7, S8) constantly used gestures (e.g., finger, pen) to point at words. Gestures were specifically used when students sought help with pronouncing difficult words (e.g., S3, S6, S8), or showed pictures to volunteers (e.g., S2, S5). Most volunteers used AR-enabled gesture sharing only when students could not pronounce the words with verbal hints alone. Both V2 and V3 used gestures and physical objects to interact with the content and students through AR mask at the very beginning of the study. V2 used a piece of white paper to underscore text from the book to create an AR mask in the shared task view (Figure 5). V3 used hand gestures for pointing when discussing some illustrations about pyramids in Maya when reading with S5. V4 was the only volunteer who used a pen to point and interact with the shared reading content as the AR mask during almost every reading session. When S8 had difficulties sounding out words, V4 pointed at sub-parts of the text in the shared task view to help using the *chunking* strategy[5].

V4 commented that being able to use the pencil to interact with students when reading through the augmented task space made her feel more social presence—"*I was with them*"—compared with just using *Zoom*. Volunteers also engaged students in the reading content by asking comprehension questions through the video communication facilitated by our communication tablet. V2 and V4 often asked content-related questions progressively during the reading, while V1 and V3 tended to ask questions after students had finished a book.

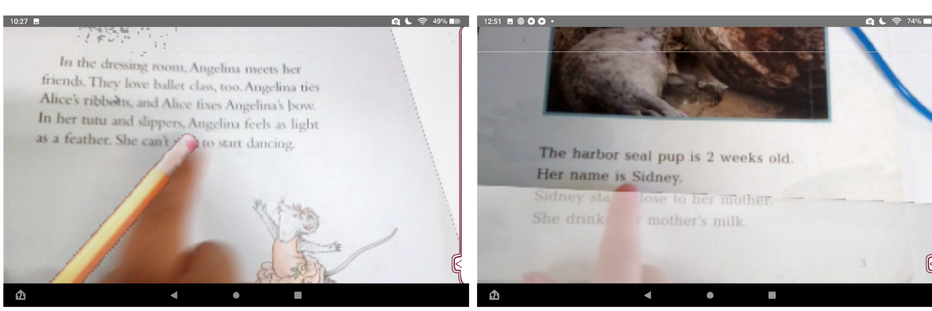

Fig. 5. Screenshots of volunteers and students read together. Left screenshot demonstrates how the volunteer used a pencil to point at specific words; right screenshot demonstrates how the volunteer used paper to underscore text.

We observed new interactions from using an AR-based video system for sharing physical objects between volunteers and students, especially in coordinating the positioning of the book correctly under the camera of the task tablet. Such interactions on adjusting the book and other objects' positions are necessary when sharing physical content is the foundation in augmented task space, to allow volunteers to follow and interact with the text through AR mask as students read. All students except S8 needed prompts and reminders from volunteers about moving the book to display the book content. However, we found volunteers didn't interrupt students every time they needed to move the book during the reading sessions, as volunteers could follow the reading content just from the audio when students read. When students had problems projecting their voices to the microphone (e.g., S1), could not read out loud (while volunteers were wearing hearing aids), or had

[5]A reading strategy that involves encouraging children to break words into manageable *chunks* to sound out the word.

really difficult books (e.g., S8), positioning the book well under the task tablet's camera became vital for the volunteers to view and understand the book content in the shared task view, in order to ask questions or provide help with gestures through the AR mask. When asking volunteers to rank the importance of different features of the system, three out of four volunteers ranked viewing content as the most important feature in this remote AR reading system, and audio communication as the second most important feature. Both viewing and sharing gestures through AR received an average ranking of four among six features in our system design. For V1, the challenge with making sure students always positioned the book well so volunteers could understand what was missing, "*really felt like an interruption to the reading*." Although V3 had no problem understanding the book content from the audio feed when reading with S5, the shared video feed on the task tablet sometimes had difficulties catching up with S5's reading speed (as he flipped pages too quickly), causing a delay in viewing the content from the shared task view. Such reading habits could make it challenging to understand the current reading context for volunteers.

Volunteers mentioned that the distractions in the school environment could be a potential challenge for engaging students in these remote reading sessions facilitated by our system. Both systems were set up in an open (hallway outside the classroom) or semi-open space (library) inside the elementary schools, which were not free from sound or noise from other classrooms. Two volunteers were also scheduled right before students' outdoor time, so towards the end of their reading sessions, other students in the school might start forming lines and talking behind our student participants in the hallway. Although V4 suggested a less distracted place or a more immersive environment would be better for her students, she commented that S7 could often re-focus fairly quickly on the reading when distracted. V1 made similar comments that other students' screams from the hallway sometimes were more distracting to her than her students. V1 also said that the distractions from the environment in these remote reading sessions were not different from the potential distractions one would have when reading in person in these schools.

5.2.2 Expectations for Students in Facilitated Remote Reading Sessions. All students were able to stay through the entire remote reading session when using our system (i.e., teachers or researchers did not need to intervene to make students sit in front of our system to complete the remote reading session). As suggested by our reading motivation questionnaires, all student participants had relatively high motivations and interests in reading before starting this deployment study. Most of our student participants (seven out of eight) joined these remote reading sessions because they were identified by the teachers as they would benefit from extra reading time with adult volunteers, or need more help working with reading comprehension. T2 mentioned that the selection criteria were similar to the prior in-person reading sessions; she chose students who are "*right on the grade level and just needed some more practice*." She avoided choosing students whose reading performance didn't meet the grade level as they already got additional services from the school. T1 had similar considerations in mind when discussing their expectations for these reading sessions. Although these expectations were not communicated explicitly to the volunteers (except V4, who was able to ask T2 briefly during a catch-up when reading with S7), all volunteers assumed such expectations and adjusted their reading strategies accordingly. For example, when S3 and S4 struggled with word pronunciation, V2 simply provided the words, emphasizing, "*the purpose here was more for them to enjoy the reading*." All students read the books they picked by themselves during these remote reading sessions. Students sometimes kept bringing the same book to read with volunteers repetitively. In those cases, students became really familiar with the book content and ended up not needing any help from volunteers (e.g., pronouncing difficult words and using gestures in the augmented view) when reading remotely. Although V3 thought S7 should be challenged with more difficult readings, he didn't push S7 to pick different books as it was more important for the student to read and enjoy the books he liked.

5.3 What social practices emerge around the use of such an AR-based system by volunteers and students (RQ3)?

Volunteers and students reported a stronger sense of closeness with each other at the end of the deployment study, suggesting an overall positive effect of our system usage on volunteer and student's sense of connectedness with each other (Table 3). Most of the self-reported scales didn't change or had negative changes for volunteers' sense of belonging with their community (Table 4). Only one question had a change equal to 0.5 Likert scale, showing more agreement among volunteers about being a part of their communities. We found similar social practices and interactions between volunteers and students transferred from in-person settings to remote settings in these facilitated remote reading sessions. However, participants discussed more challenges in finding opportunities for social connectedness when using our system.

Table 3. Changes in the sense of closeness with the other reported by volunteers and students. The lead role in each pair is the self-subject. For each pair, we reported the average and the standard deviation of the responses. The changes are color-coded, with green for positive changes and orange for negative changes.

(on a 1-5 scale)	Week 1	Week 8	Changes
Student – Volunteer (don't know – very close)	3 (1.31)	3.75 (1.16)	0.75
Volunteer – Student (don't know – very close)	2.38 (0.52)	3 (1.32)	0.62
Volunteer – Teacher (don't know – very close)	2.75 (1.71)	3 (1.63)	0.25

5.3.1 Social Practices and Experiences in Facilitated Reading Sessions. Book content served as a preamble for volunteers and students to discuss and share their personal experiences and stories, which is similar to volunteers' and students' practices during in-person reading sessions. We observed an average of 1.95 conversation exchanges per reading session (SD = 1.92). Volunteers often prompted students to talk more about their lives, by asking questions related to the book content. For example, when S3 was reading a book about mice, V2 asked her if she had seen a mouse in real life before. Volunteers sometimes shared their own personal stories as well with students. V1 talked about her dog who has the same name as the dog from the book she was reading with S2. The ability to share physical objects through the shared task space provided more opportunities for personal conversation exchanges during the remote reading sessions as well. For example, V2 noticed a wand-like pen that S4 kept using to point at the book when she was reading and started a conversation around that pen to get S4 to talk about something she liked. Volunteers and students also greeted each other at the beginning of a reading session, and said goodbye to each other at the end of the session. We only observed seven sessions (out of 71 sessions) where greetings or goodbyes didn't happen. Following the greetings, volunteers often asked students about their previous weekends, recent holiday plans, and any exciting trips or events students had recently. Most volunteers (V1, V2, and V4) took handwritten notes on separate papers and notebooks about what students shared during these conversations so they could follow up with the students about those exciting things in the following reading session (e.g., S4's winter vacation, S7's weekend trip to the zoo). Volunteers reserved dedicated time during the reading sessions to celebrate any special events with students. S2's birthday was on the same day as her last reading

Table 4. Changes in the sense of belonging with the community reported by volunteers. For each question, we calculated the average of the responses and reported the standard deviation. The changes are color-coded, with green for positive changes and orange for negative changes.

(on a 1 to 5 scale)	**Onboarding**	**Debriefing**	**Changes**
Q1. I feel comfortable in my community (strongly disagree to strongly agree)	5 (0)	4.75 (0.5)	-0.25
Q2. I don't have many friends in my community (strongly disagree to strongly agree)	2.25 (1.5)	2.25 (1.26)	0
Q3. People in my community make me feel wanted and accepted (strongly disagree to strongly agree)	4.75 (0.5)	4.75 (0.5)	0
Q4. I feel like I am an important member of my community (strongly disagree to strongly agree)	4.75 (0.5)	4.5 (0.58)	-0.25
Q5. I wish I were not a part of my community (strongly disagree to strongly agree)	1 (0)	1 (0)	0
Q6. I am a part of my community (strongly disagree to strongly agree)	4.25 (0.98)	4.75 (0.5)	0.5
Q7. I am disliked by others in my community (strongly disagree to strongly agree)	1.75 (0.98)	1 (0)	-0.75
Q8. I am committed to my community (strongly disagree to strongly agree)	5 (0)	4.75 (0.5)	-0.25
Q9. I am supported by my community (strongly disagree to strongly agree)	5 (0)	4.75 (0.5)	-0.25
Q10. I am accepted in my community (strongly disagree to strongly agree)	5 (0)	4.5 (0.58)	-0.5

session with V1. After she shared about the upcoming birthday with V1 in her previous session, V1 created a birthday card to share with S2 by showing it through the communication tablet's camera in *Zoom*, and wished her a happy birthday during their last reading session.

However, the interactions volunteers had with teachers were minimal. Teachers mostly talked to volunteers directly at the very beginning of the study, when they introduced their students to the volunteers. In most reading sessions, volunteers couldn't see the teachers' faces because our system's height was not intended to capture a standing adult next to a seated child. Besides, T1 was often busy managing her class and attending to other students during reading time, so she was not able to talk to volunteers once she finished setting up the system for students. T2 was able to do a brief greeting with volunteers before students started reading. As V3 commented, teachers were just "*in and out*", and he didn't interact with them a lot during the study. Despite the minimal amount of interactions volunteers had with teachers, V4 said it was comforting knowing the teacher was there at school with students, and helping facilitate everything for these remote reading sessions.

Video communications through the communication tablet played an important role in volunteers' and students' social practices during the remote reading sessions. Volunteers and students referred to the communication tablet (i.e., looked up at the videochat interface in the communication tablet) when they engaged in personal conversations during the session, listened to volunteers' instructions or hints for sounding a word, or discussed book content. Both V3 and V4 appreciated the ability to view students' faces and share content at the same time, which was supported by our system. Before joining the study, V3 did remote volunteering with a local middle school and was only able to view the book content as the priority on the screen when a reading session started. Because all volunteers joined the sessions from their homes where masks were not needed when COVID-19 restrictions were still in effect in most public places, V4 commented that videochatting without face coverings helped students know that she was not too stern when helping them with words they really struggled with. However, most students were required to wear masks in their schools during the study, following the school district's guidelines (except the last couple of sessions between V4 and S7, S8). Some students were able to unmask during the reading sessions, as the system was often set up in a location relatively distant from other people. V4 hoped that students didn't have to wear facial masks during the study, as "*seeing their face and their smile mattered a lot*" to her.

5.3.2 Challenges in Building Social Connections. Volunteers found many challenges in finding opportunities for social connections during the study, when comparing the reading sessions facilitated by our AR system to their prior experiences with in-person or other remote reading. Many social opportunities volunteers had with students during in-person or other remote reading sessions were provided by the context where the reading sessions happened. Such context helped volunteers learn more about the student's personal life and school life, providing opportunities to further their relationships. For V1, the context came from the decorations and drawings on the walls of students' classrooms if she volunteered at school, or interruptions from students' pets or siblings if students were at home. Volunteers also learned such context from students' interactions with other students. Before this study, V3 did remote volunteering with a group of three students. He commented that he was able to learn more about the students from their interactions and conversations with each other. However, such context and opportunities could be missing when the system only focuses on the singular activity and a limited environment, where volunteers might struggle to find these contexts to learn more about students and connect with them.

Stress and struggles with new technology usage also made it difficult for volunteers to find opportunities for social connections with students in our study. Although all of our volunteer participants used many technology tools and had experiences with various videochat applications, managing a new system at the same time as engaging students during a reading session was still challenging. V2 mentioned that she was so stressed with the technology that she didn't have much capacity to think about the conversations with students that could let her know more about the students. When asked about what they would have done differently during the debriefing, V2 commented that she wished she could be more relaxed and not worry too much about the technology for these reading sessions.

All of the personal conversation exchanges we observed in our study were initiated by volunteers. Our student participants with this specific age group (second grade) needed extra support if we expected them to initiate a conversation during the reading session. As T1 mentioned during the debriefing, second graders didn't know how to interact with adult volunteers, and this study was also the first time they interacted with adult volunteers at schools. From volunteers' perspective, this lack of experience interacting with adult volunteers could lead to the impression that "*students were not interested in volunteers*" (V1). V4 talked about her strategy of interacting with second-grade students, saying that it was effective to keep asking students questions beyond yes or no answers, as "*you cannot expect a back and forth conversation*" with the students. V4 also mentioned she often prepared in her head some questions to ask students before each week's session, as well as taking notes about anything students mentioned that could serve as conversation starters next time.

6 DISCUSSION

Based on the findings from the field, we present design implications for technologies to support intergenerational activities and communications in various contexts. We also discuss potential infrastructure constraints to consider when designing technologies for older adults' usage in their living spaces. We reflect on our research practices working with our community partners and older adults in the deployment study, to provide suggestions for other researchers from the community who want to deploy their system in a similar setting. We then discuss limitations and future work.

6.1 Implications for Technologies to Support Intergenerational Activities and Communications

Our participants shared many challenges they had regarding their experience reading and connecting with each other using our system for remote reading, especially in accessing shared activity content, coordinating over-camera work for the augmented shared task view, and finding rich contexts for social connections. Situating our findings in previous work about technology-supported intergenerational communication and activities, we discuss considerations for future social technology design to support intergenerational activities.

6.1.1 Supporting Equal Access to Activity Content. Viewing and accessing activity content plays a critical role in people's experiences with technology-facilitated remote activities. Three out of four volunteer participants considered viewing content as the most important feature of our remote reading system. The content shared in the task space served as the common ground for all interactions and communications that happened during technology-facilitated shared activities. In our system design, the shared physical content (e.g., books) in the task space acts as a foundation for all AR-enabled tangible interactions in the space. We specifically adopted an asymmetric approach when designing this interaction for sharing and accessing the content, so that only students who had physical access to the books shared in the remote reading session, who were also leading the presentation of the content. Previous literature in designing technology for intergenerational communication often suggests an asymmetric design to address different technology requirements by children and older adults in technology-facilitated communication (e.g., [19, 55]). Such asymmetric design can be successful in facilitating remote intergenerational play, but can also limit the possibilities of interaction for both generations [21]. In our study, part of the challenges with viewing and accessing content from the volunteers' side was related to the device form factors and the screen real estate when interacting with the shared content. Technology design should consider these factors to provide enough access to the activity content for all participants. On the other hand, design for technology-facilitated shared activities can still follow an asymmetric design approach, but leverage different modalities (digital and physical) to support participants' equal access to the activity content. For example, a design could provide volunteers with access to digital reading content in their task space, and still allow students' usage with their physical books. This system design also needs to support translating interactions between different modalities (i.e., a tap on the digital content is presented as the projection of a hand gesture on the other person's view of shared task space).

6.1.2 Supporting Better Coordination over Activity Content. Except for S8, all other student participants needed to constantly coordinate with volunteers about positioning the part of the book they were reading under the camera for sharing (section 5.2.1). This coordination over camera work for properly capturing and sharing content with the remote participant is vital, when using a collaborative AR system, since both sides need to see the same content for communication and work over the shared view (e.g., pointing at the same word to figure out its pronunciation when reading). Students' age group could be one of the factors that led to their struggles with positioning the book and coordinating with volunteers over the reading content. Such coordination in the study was only facilitated by audio, and sometimes students struggled to understand volunteers' instructions on how to move the book (e.g., S3). V4 suggested adding a ridge to the stand for a better indication of where to position the book. Researchers studying technology-facilitated remote collaboration have been investigating different design features to support coordination between collaborators over tasks (e.g., [52, 85]). Visualization of different information or interactions (e.g., [8, 46]) can help people better coordinate over tasks in remote collaboration. When designing technology to support shared activities, researchers and designers should consider having additional visual cues on the shared task space to facilitate coordination. Such visual cues can be simple instructions guiding students to move the book as they read, or prompting students when triggered by volunteers. As V1 pointed out, constant coordination over positioning the book could reduce meaningful social interactions in the remote reading sessions. It is important that technology design can help facilitate coordination over activities for better social outcomes.

6.1.3 Supporting Context Understanding for Social Connections. Prior works (e.g., [27, 71]) in studying communication technology for intergenerational connection in a family context (e.g., grandparent-grandchild, parent-child) often emphasize the importance of supporting the shared activities (e.g., reading, play) and engaging children during the remote communication, as these activities help provide common ground for connections. Our participants also agreed that reading books serves as "*the vessel*" for social connections (V4). However, our participants discussed the struggle with finding opportunities for relationship building and social connections beyond reading (section 5.3). When comparing the reading sessions in this deployment study to the in-person or remote ones, our volunteer participants talked about the context and environment of the reading sessions, which are often not related to the reading activity itself but provide opportunities for social connections. V1 mentioned that contextual information (e.g., students' drawings on the wall, their pets at home) often led to conversations that enabled her to learn more about the students she was working with. In our system, the physical constraints with a fixed camera and stand height and the dedicated task—which was intended to create an engaging reading experience—can limit the access to learning the rich context around students for more social connection opportunities during remote reading sessions. Learning such context is vital for social connections in our study's setting, as our volunteers and students were new to each other and spent most of their time building rather than maintaining their relationships. To design technology-mediated shared activities in a similar relationship setting, supporting context building and understanding is important for social connections. For example, systems can have built-in features that prompt students' active sharing of their updates or things they are interested in (e.g., their recent drawings, Lego they built). We can leverage alternative technology platforms for remote shared activities (e.g., 360-degree camera) that can capture richer context and the environment, or build additional channels to feed in information about the students to provide a rich context for the shared activities. We can also leverage AR/VR platforms to create a shared virtual environment to facilitate shared activities in a rich context.

6.2 Designing with Technology Infrastructure Constraints

Our findings from deploying the system in the field highlight the technology infrastructure constraints that researchers and designers need to consider when developing technology systems for similar contexts. For older adults, different living arrangements can pose constraints on technology designs. Older adults living with extended family members (such as V2 in our study), or living in assisted and independent living facilities might have limited internet bandwidth, which can be challenging for using systems that require multiple video streaming sessions running at the same time, which has become a common setup now with increasing multi-device usage in remote communication. In our deployment, we provided V2 with a dedicated WiFi hot-spot as a temporary solution for completing the study. However, it is important to work with these constraints when designing beyond a single deployment study and create features that can operate with limited connectivity using strategies such as caching, which allows users to access crucial functionalities and information without being fully dependent on a stable internet connection at full bandwidth.

These design considerations can benefit the school and other community settings as well, for supporting scenarios that require system usage at scale.

6.3 Working with Schools and Teachers as Community Research Partners

One of the challenges we faced when planning the study was forming a connection with local schools to deploy our system for the study. We started by recruiting teachers who had former connections with the volunteer program we had connections with, as research partners (section 4.1). We conducted two workshops with recruited teachers to get their feedback on our system design and research plan. We focused our efforts on aligning our research plan with their schools' schedule and their work schedules, to make our research plan more feasible throughout the school year. With the feedback from the teachers and the connections we formed with them, we were able to be specific about our study plan and articulate the potential impact of our study on schools in our research application to the local school district. Echoing prior work in creating productive partnerships in community-based research [54], our experience planning the field study shows the importance of developing relationships, aligning goals, and building rapport, to overcome barriers in community-based research.

Our study also benefited from the school district's experience with technology and remote learning from the last couple of years in response to restrictions and policies during the COVID-19 pandemic. Our teachers showed more willingness to consider incorporating our study into their busy class schedules and more confidence in helping facilitate the remote reading sessions from their schools.

6.4 Empowering Older Adults with Technology Confidence in Deployment Study

Although most of our volunteer participants felt comfortable working with technology (section 4.4), they still felt stressed when technology breakdown happened and they needed additional support (section 5.1). In our study, their experience with technology could directly impact their experience with the activity. We initially planned to only facilitate the first several weeks' remote reading session and pushed volunteers to be more independent with the technology usage. After the first week's study, we realized that even for more technology-proficient volunteers, having us join the session did give them more confidence in technology usage, and help them focus more on the activity and interactions with students. We continued the study with at least one researcher joining the reading sessions (with our face camera off to minimize interruptions). We also provided additional technology support for V2 who felt less confident with technology usage, helping her with the setup process through phone calls every time before her scheduled reading session.

Reflecting on our experience working with older adults in this study, we think it is important to help older adults build their confidence in new technology and keep their motivations throughout the study. More technology training sessions, choosing devices they are already familiar with, adapting instructions to their technology practices can all help build their confidence with new technology. All of our volunteers were motivated by working with students, and contributing to the community and the research. It is also important that we help them keep such motivations in this study (not too frustrated by the technology). We shared students' photos from the field and thank-you notes from parents (with proper permissions) with our volunteers to make them "*more connected*" with their local community, especially during the time that the community was figuring out how to live with the COVID-19 pandemic.

6.5 Limitations and Future Work

The insights generated by our study are limited by the demographics of our participants and the community we engaged with during the deployment. All of our participants were recruited from the same suburb near a metropolitan area in the Upper Midwestern United States. Our student and volunteer participants had access to a diverse range of technologies: each student had their own *iPad* at school; most of our volunteer participants used wearable or smart home devices besides their smartphones and laptops/desktops. All student participants were from second grade, and we considered their attendance rates during the recruitment to ensure completion of this study. Students from different age groups might have different reading and social practices when interacting with volunteers during these remote sessions. Volunteers who have less access to technology might experience different challenges using our system when reading and working with students remotely.

We took a technology probe approach when designing our system prototype and deploying it in the field. This research approach allowed us to generate insights about the usage of the system features, feasibility, and desirability from the real-world setting. However, this method also limited direct comparisons between an AR-enabled video system and traditional video-based media spaces for potential insights on the specific effect of AR features. Some of the findings on social connection-related outcomes could come from using a videochat based media space as well as using AR-related system features that enable interactions with physical objects. For future investigations, researchers can conduct controlled studies to better understand and compare the impact of different technology systems on social outcomes.

Although we only evaluated our system in the context of remote reading, our system was designed to support various intergenerational tutoring and social activities. Some of our student participants (e.g., S1, S5) mentioned that they would like to use our system to play puzzles or Lego with volunteers. Future research could evaluate such applications. Besides, we only evaluated our system among school volunteers and students, who had different social connection goals and expectations than those outside the school settings (e.g., intergenerational relationship between grandparents and grandchildren). Future research could consider investigating a similar set of questions with a different relationship context.

7 CONCLUSION

Prior research has shown the importance of shared activities in technology-mediated communication, for building connections and understanding between individuals of different ages. Our study explores the potential of technology to support intergenerational connections through remote collaborative reading, focusing on the use of a tablet-based AR system in a community setting. We designed and developed the system which focuses on supporting tangible interactions and existing practices in intergenerational reading activities. We conducted a field deployment study over six months to investigate the usage of the system in a real-world setting. Our findings provide empirical insights into older adult volunteers and students' reading and social experiences during technology-mediated reading sessions. Our work reveals challenges from the field study, which sheds light on future design opportunities for social technology to support intergenerational connectedness in a community setting.

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