Embodied Notes: A Cognitive Support Tool For Remote Scientific Collaboration in VR

Monsurat Olaosebikan
Tufts University
Medford, MA, USA
monsurat.olaosebikan@tufts.edu

Claudia Aranda Barrios
Tufts University
Medford, MA, USA
claudia.aranda_barrios@tufts.edu

Lenore Cowen
Tufts University
Medford, MA, USA
lenore.cowen@tufts.edu

Orit Shaer
Wellesley College
Wellesley, MA, USA
oshaer@wellesley.edu

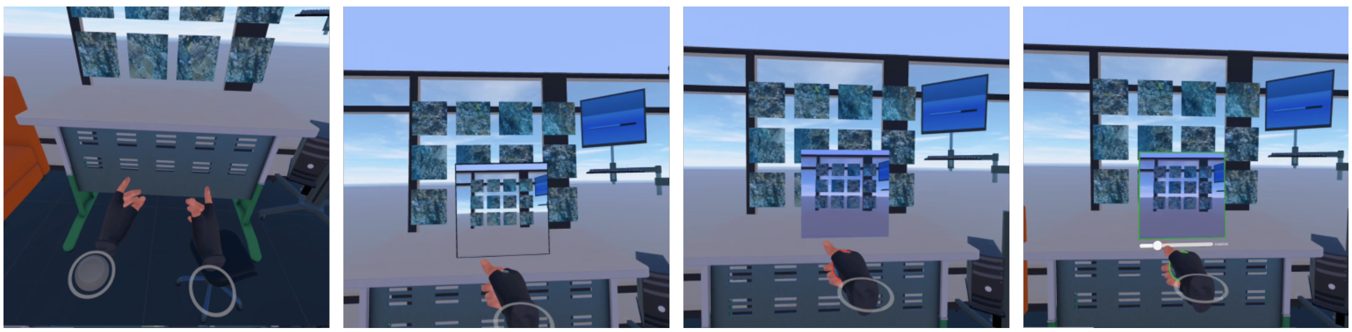

Figure 1: In Embodied Notes, notes are represented as a) thought bubbles (spheres). b) Users can take pictures to provide context for the note, c) record a note using their voice and d) replay the note using a shaking gesture. Quadrat images shown in Figures 1a, 1b, and 1c copyright (c) Underwater Earth / XL Catlin Seaview Survey / The University of Queensland.

ABSTRACT

Scientists collaborate remotely across institutions, countries and continents. However, collaborating remotely is challenging. Video-conferencing tools used for meetings limit the cognitive practices that collaborators can partake in. In virtual reality (VR) users can gain back some of the spatial and social affordances present in collocated collaboration, as well as benefit from interactions that would not be possible in the real world. We introduce Embodied Notes: a cognitive support tool designed to be used in a collaborative virtual environment.

CCS CONCEPTS

• **Human-centered computing** → **Collaborative and social computing systems and tools**; **Virtual reality**; **User interface design**.

KEYWORDS

virtual reality, remote collaboration, note taking

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1 INTRODUCTION

Scientific collaborations have been and continue to be instrumental in advancing science and accelerating research in many fields [5, 6]. Many of these collaborations are conducted remotely as expertise is often spread out in multiple institutions. Since the COVID-19 pandemic this is true for even collaborations within an institution. Research in remote scientific collaboration has explored the use of email, audio conferencing [1], video conferencing [32], tele-presence [18, 20], groupware [24], and custom domain specific applications [17, 23] to make collaboration across distances easier and more productive. However, remote collaboration poses several challenges to a team including alignment of incentives and goals, awareness of colleagues and their context, establishing trust, and a lack of motivating sense of presence with others [28, 34]. Additionally, video-conferencing, the standard for synchronous meetings in scientific research, limits the kind of cognitive offloading - the process of using physical action to reduce mental load [40], that can be done during a collaborative creative exploratory or problem solving process compared to a collocated scientific group meeting with access to physical whiteboards, sticky notes, and space [41]. Reality Based Interaction (RBI) [19] styles such as virtual reality (VR) leverages users' existing knowledge and skills of interaction with the real non-digital world such as naive physics, spatial, social and motor skills. By drawing upon existing skills of interaction with the real non-digital world such as touch, gestures, and physical manipulation, RBIs "offer a natural, intuitive, and accessible form of interaction that reduces the mental effort required to learn and operate computational systems" [43]. In recent years, VR headsets have become pervasive and technologically robust enough to support professional collaboration. We hypothesize that VR provides affordances for supporting cognition in a scientific group setting that video-conferencing does not or cannot provide, and propose that we can use its affordances to improve remote scientific collaboration.

Our current investigation focuses on note taking as a critical cognitive support tool [36]. Erick Greene a professor of ecology and evolutionary biology describes notes as "the main source of ideas that take my research in new directions" and not only a mere record of observations [36]. During a research meeting, in-person or remote, participants often take notes. Note taking during a meeting is useful for capturing ideas, important information, questions that come up that warrant investigation after the meeting, and action items for the next meeting. VR applications that implement note taking have used a variety of input methods. For example, in Horizons Workrooms [45], users can use their computer and physical keyboard in VR to type notes using their preferred desktop application. In Spatial [44], users can write on sticky notes visible to all in the room by pressing keys on a virtual keyboard or using the speech to text functionality. Research has explored using ray-casting to write letters for text entry [15] and tablet and stylus tracking for writing long hand notes in VR [9, 21, 38]. However, such methods have several limitations: virtual keyboards are slow to use, physical keyboards require being seated at a desk or wearing extra gear to hold the keyboard [37], speech to text is error prone requiring extra cognitive load to correct mistakes [2], and using extra peripherals (tablets, pens) can be cumbersome. To overcome some of these challenges we propose the concept of Embodied Notes: a cognitive support tool designed to be used in a collaborative virtual environment. Embodied Notes enables users to take multi-modal notes in VR using a predefined set of gestures without extra peripherals beyond the headset and controllers. In the design and preliminary evaluation of Embodied Notes we explore applying reality based interaction (RBI) principles and design trade-offs [19]. We aim to minimize the gulf of execution from thought to notes for users, and to document trade-offs that may result in greater cognitive support for the user. In this paper, we present the design and implementation of Embodied Notes, a note taking tool for remote scientific collaboration in VR.

2 RELATED WORK

In her book *Extended Mind* [36], Annie Murphy Paul synthesizes findings from the fields of embodied, situated, and distribution cognition to propose a framework for "thinking outside the brain". Her framework draws upon Clark and Chalmer's seminal article titled "The Extended Mind" [10] to define thinking outside the brain as "skillfully engaging entities external to our heads—the feelings and movements of our bodies, the physical spaces in which we learn and work, and the minds of the other people around us—drawing them into our own mental processes." Paul specified nine principles for extending the mind: 1) offload information into the world; 2) transform information into an artifact and then interact with it; 3) seek to productively alter one's state for improving mental labor; 4) re-embody information; 5) re-spatialize information; 6) re-socialize information; 7) generating cognitive loops; 8) thinking by creating cognitively congenial situations; and 9) thinking by embedding extensions in our everyday environments. In VR, scientists can more readily engage in these extended mind practices than in current state of the art video conferencing, taking advantage of the spatial and embodied interactions facilitated by VR applications to absorb complicated material and collaborate to develop new insights.

In his book *SuperSight* [41], David Rose proposes that immersive technologies can help boost semantic and episodic memory compared to teleconferencing which can lead to fatigue [3, 30]. Engaging users' sight, hearing and body position during learning, better positions them to recall information at a later time [41] and potentially create connections between new and existing knowledge using episodic memory. With VR we are able to engage these senses to make sense of information. Research in immersive analytics, the use of engaging, embodied analysis tools to support data understanding and decision making [8, 27], has explored using VR for economic analysis [4], network visualization [12], biological data visualization [39], multivariate data visualization [11], trajectory data [16], textual analysis [26], and scientific discovery [14, 22]. However, very few [26] immersive analytics tools include the ability to take notes despite note taking being an important aspect of conducting scientific research [29]. Other research in VR has explored digital sticky notes for spatial ideation [25] and using peripherals like digital tablets [9] and smartphones [25] as input devices. However, these were limited to single user scenarios and did not explore what it might look like to create and share notes in a collaborative setting. Our research seeks to fill this gap, by exploring the design and development of a cognitive support tool designed to be used in a collaborative virtual environment: Embodied Notes.

3 NEEDFINDING STUDY

To identify the needs of scientists collaborating remotely we conducted a qualitative study where we observed two interdisciplinary groups of coral reef scientists (n=14) including professors, graduate students, and post-docs. Their research areas spanned computer science, marine biology, mathematics, computational biology, coral biology and biochemistry. Each group met in VR over a period of 4 weeks from June-July 2021 to discuss their ongoing research (Fig 2). They met using the meeting application Spatial [44] where users are able to import multiple data formats including 3D models, pdfs, and images and create avatars that resemble themselves. One group also used Nanome [31] for exploring biological data. During the meeting we recorded their interactions, and after each meeting we had participants complete a survey and a group interview to gain insight into their experiences with meeting in VR. We conducted a thematic analysis [7] to analyze the transcripts from each group discussion as well as the open responses to the surveys. Our analysis indicated that the scientists wanted to be able to communicate with others through both private and public channels and felt frustrated with the inability to write personal notes or quickly write down a continuous stream of thoughts as one would on pen and paper or with a physical keyboard. For example, they wanted to ask a question but not interrupt the current flow of conversation, write a note for themselves to explore or extend an idea further, and to share a thought privately with another individual. In video meeting applications like Zoom, that scientists traditionally use, they can send private messages to each other and put a question in the chat. For in-person meetings they can send an email or use apps like Slack when their laptop or phone is in reach. The scientists expressed a need for similar functionality in VR meetings. They also expressed the need for a multimodal summary of the meeting which includes the dialogue, artifacts produced (e.g. charts, post it notes), spatial arrangement of artifacts, and the path one took to explore the virtual environment. Since users rarely want to review an entire meeting from beginning to end but rather revisit key points or important content. In this paper, we address the need for note taking in collaborative VR meetings. In the next section we identify design requirements for a note taking and communication tool.

Figure 2: Scientists in needfinding study meeting in Spatial and Nanome to discuss research over 4 weeks

3.1 Design Requirements

Based on findings from our formative study, we synthesized the following requirements for the design of a note taking and communication tool for a remote collaborative scientific meeting in VR.

> **DR1: Easily create and delete multimodal notes** Users should be able to create and delete notes quickly without losing their train of thought. Notes should be multi-modal including images and audio to allow users to recall the context in which a note was taken.
>
> **DR2: Notes are private by default** A note should only be visible to the owner unless explicitly shared.
>
> **DR3: Easily share a note with all meeting participants and/or specific individual(s)** Users should be able to share a note with selected individuals. This should include people present in the current meeting and those absent who are part of the larger group.
>
> **DR4: Easily maintain context** Users should remain immersed while taking notes to ensure they do not miss any aspects of the meeting or lose their frame of reference.

4 EMBODIED NOTES

To address the need for continuous personal note taking and private communication in collaborative VR meetings as articulated in the design requirements above, we introduce Embodied Notes, a tool for capturing and physicalizing stream of thought notes while participating in a VR meeting. The notes are private by default but shareable with others. With Embodied Notes, users can record a note using their voice (users are automatically muted while recording) and take pictures to provide context for the note. The notes are represented as thought bubbles (spheres) where the outer texture of the sphere provides the visual context of where the note was taken. The representation of notes as 'thought bubbles' is inspired by the marble answering machine [13] and tangible message bubbles [42]. Important considerations for the design of Embodied Notes was ensuring privacy when recording notes and providing observable cues for others during note taking. In the following sections we describe how users interact with notes, and the design trade-offs we made in designing these interactions.

4.1 Creating a Note

Users create a note by grabbing a new transparent thought bubble from a 'pocket' attached to their left hand (Fig 3). To record audio the user brings the note towards their mouth as if to speak into a voice recorder. The outline of the note and the users' avatar becomes red to indicate that they are recording and muted to others. Once the user is done recording they bring the note close to their mouth again to stop the recording and return to an unmuted state. This allows users to continue to interact with their environment while recording. To take a picture (Fig 4) to accompany a note the user presses the trigger button on their controllers while holding the note to activate a camera window. The user is given a few seconds to frame their intended target before a picture is taken. Only the creator of the note can see and interact with the bubble, as all notes are private by default. Inspired by the RBI framework, this interaction employs users' knowledge of naive physics, body awareness and environment awareness skills to keep users immersed in the environment at the potential expense of efficiency, compared to a traditional point and click interface or using a virtual keyboard. We intend to conduct a user study to identify the strengths and limitations of this approach.

4.2 Storing a Note

The user stores a note in a notebook (Fig 5). The user summons the notebook by holding their palms upwards as if they were holding a book open after which a notebook will appear in their hands. The notebook is divided into three sections (questions, notes, summary) corresponding loosely to the Cornell note taking system [35] where notes are arranged based on the nature of their content. The user

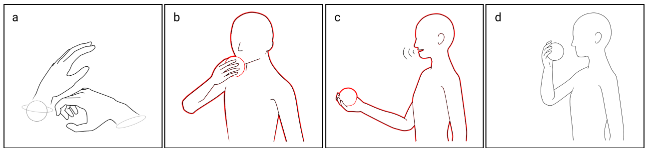

Figure 3: Creating a Note. a) The user grabs a new note from their left pocket, b) moves the note close to their mouth to start recording. A red outline around the note indicates to the user that they are recording and a red outline around the user indicates to everyone else that they are creating a note. c) The user dictates their note d) then moves the note close to their mouth again to stop recording.

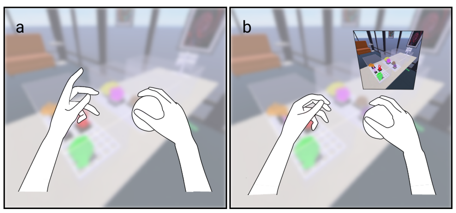

Figure 4: Taking a Picture. a) While holding a note, b) the user presses both triggers to take a picture

turns pages in the book by waving their hand left over the book to turn to the next page and right to turn to the previous page. The user closes and hides the notebook from view by holding the notebook with both hands and completing a close book gesture. According to the RBI framework this interaction engages users' naive physics, body awareness, and environment awareness skills enabling users to store notes where they can easily find them later, with the potential trade-off of being less efficient for storage but more efficient for retrieval.

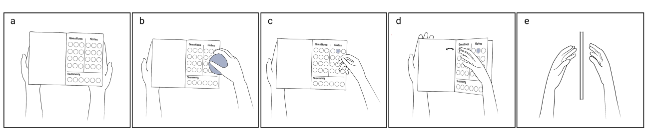

Figure 5: Storing a Note. a) Holding both palms upwards, a notebook appears in front of the user. b, c) The user can then place notes anywhere on the page. d) Waving a hand in front of the notebook to the left turns to the next page, waving to the right turns to the previous page. e) Grabbing the book with both hands and moving both hands closer to each other as if to clap hides it from view.

4.3 Playing a Note

The user shakes a note to trigger playback of the audio recorded within the note (Fig 6). As the audio plays any pictures taken while recording are shown in sync with the time during the recording they were taken. While listening to the note the user is automatically muted. This interaction draws upon users' naive physics and body awareness skills to draw a metaphor between shaking something and hearing a sound. The trade-off here relates to ergonomics as it could become physically tiring to shake notes to hear them.

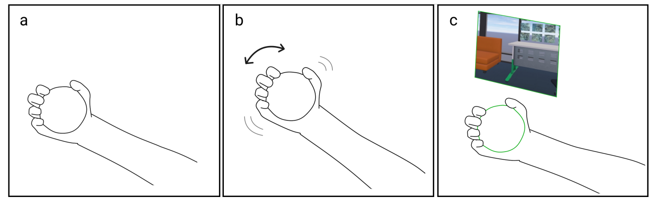

Figure 6: Playing a Note. a) Grabbing a note and b) shaking it plays the recording. The sphere is outlined in green to indicate it is playing and c) the stored pictures are looped through in sync with the time it was taken during the recording.

4.4 Deleting a Note

The user throws a note up towards the sky to destroy it (Fig 7). The note subsequently pops (disappears). This interaction utilizes users' naive physics, body awareness, and environment awareness skills to imagine the note as a bubble that disappears once it reaches certain conditions. Trade-offs include the ergonomics of throwing the note and expressive power (the action cannot be undone to retrieve a deleted note).

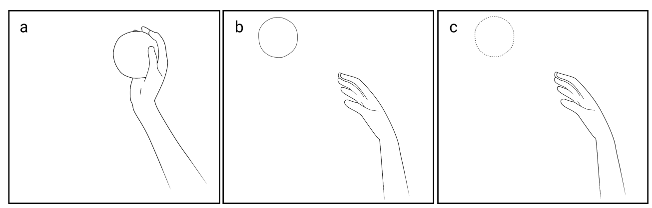

Figure 7: Deleting a Note. a) A user grabs a note and b) throws it into the air c) destroying it.

4.5 Sharing a Note

As all notes are private by default, the user must explicitly share them for the bubble to be visible to others. To make the note available to everyone the user throws the note towards the ground (Fig 8). Once the note hits the ground a copy of the note is made visible to everyone in their right hand pocket. To share a note only with specific individuals the user can use their laser pointer to point at the person and throw the note in their direction for a copy of the note to appear in the recipients right hand pocket (Fig 9). If the desired recipient is difficult to pinpoint (e.g. in a crowd) the user can point in space and a selection menu appears listing users to choose from. Users' who have received a note will experience a vibration on their right controller and can extract the note from the pocket on their right hand. These interactions build on users' naive physics, social awareness, body awareness, and environmental awareness skills. The trade-off here is expressive power. Sharing a note shares the entire note and doesn't give the user a way to highlight specific parts of the note for the recipient to focus on in favor of simplicity.

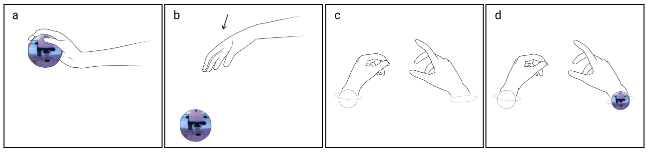

Figure 8: Sharing a Note (Everyone). a) The user shares a note with everyone by b) throwing it to the ground. c) Each user in the environment receives a copy of the note d) which appears in their right pocket.

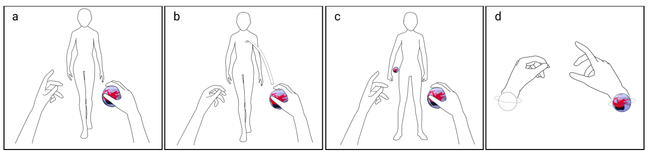

Figure 9: Sharing a Note (Individual). a) The user shares a note with a specific person by holding the note in one hand and pointing at the person. b) A laser is shown to indicate the users' selection. c) A copy of the note is shared with the selected person in their d) right pocket.

5 IMPLEMENTATION

Embodied Notes, as illustrated in the concept video and below (Fig 10), is implemented using the Unity game engine. Currently, we have creating, playing, and storing a note triggered with buttons and are working on transitioning them to be triggered by the gestures illustrated above. Deleting a note is fully implemented and sharing a note is in development.

Figure 10: Implementation of Embodied Notes in Unity. a) User playing a note. b) User placing a note in their notebook. c) Users exploring the coral lab. d) User sharing a note with a colleague out of sight using a menu. e) User sharing a note with a colleague by pointing at them while holding the note. f) User receiving a note in their right pocket from a colleague. Coral holobiont image shown in slideshow in Figure 10a copyright Dr. Hollie Putnam. PowerPoint slide shown in Figure 10d by Dr. Hannah G. Reich. Quadrat images shown in Figures 10e, 10f copyright (c) Underwater Earth / XL Catlin Seaview Survey / The University of Queensland.

Our implementation consists of a virtual coral lab, similar to physical environments in which scientists collaborate in person (see Fig. 10c). Normcore [33] is used for networking to enable multiple people to explore the lab at the same time. The virtual lab space is designed to include common instruments (e.g. dissecting microscopes, reef tanks, map table) found in real coral research labs. Users are able to use smooth locomotion and teleportation to travel around the room. As implemented, the Coral Lab will enable us to test new interaction techniques with real world data and scenarios.

6 PRELIMINARY EVALUATION

We conducted a preliminary evaluation of the design with 10 scientists (6 of them also participated in the needfinding study). We introduced the concept, showed the concept video, and asked for their feedback on Embodied Notes. Overall, the scientists were receptive to the concept of Embodied Notes. They liked the representation of a note as a tangible object: "*I really liked the question bubble*", and a sphere in particular: "*The sphere is very inventive it's super creative*" and expressed a need for expanding the input modalities to include a keyboard and whiteboard for writing equations and sketching diagrams. An additional feature the scientists suggested is to attach notes to specific objects in the virtual environment for example placing questions near the relevant poster or having a designated "pocket" for them: "*sometimes you have a question related to something specific that you're looking at, so would it be possible to have a question and tie it to a poster, for example, and you know that the person that's created this space [...] can go and answer it and I think that might be helpful*". Considering the notebook metaphor, participants suggested an alternative - a dock that is made visible when the user looks down: "*I think it might be easier if your bubbles appear at the bottom like your Mac [...] so you don't obstruct your view, or you don't have to open something special [or] separate to get access to them*". The participants also stated that having a recording of the meeting with a timestamped timeline of when a note was taken with its transcription would be beneficial: "*some sort of automatic transcription for the vocal notes [...] that's like searchable and readable, rather than having to go back and listen through [..]*". They also stressed the importance of having the notes exportable in a format that doesn't rely on a specific service or software: "*[I'd] want to be able to have some way to export as plain text that's consumable anywhere that's not tied to a particular [platform]*". We note that the design requirements investigated in the preliminary study were not specifically tailored to scientific scenarios. In future work we will tailor the design requirements more closely to scientific collaboration.

7 CONCLUSION & FUTURE WORK

We have presented the motivation and initial design for Embodied Notes - a design for a new system that is based on needs identified in a study, to support scientists. We plan to refine the design of Embodied Notes based on the preliminary feedback, complete its implementation, and conduct a user study of the tool in the context of a scientific collaboration meeting in the multiuser VR coral lab we developed. Our goal is to identify ways in which note taking in VR can support and enhance the cognitive and creative processes of scientific collaboration.

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