

Appendix A

VR Office Application Descriptions

Spatial.io . Founded in 2016 (*Spatial — About*, n.d.; Casteel, 2021d), Spatial allows users to collaborate through a variety of HMD devices (Oculus Quests, Vive, HoloLens, etc.) and also through desktop application support. Up to 32 users can meet within one of seven environments to collaborate where they can share files (including 3D models), share their screens, browse the internet, present, and write on sticky notes and in 3D space. Spatial creates an avatar of the user using a supplied photo to create a "3D-realistic avatar".

MeetinVR . Founded in 2016 (*MeetinVR*, n.d.; Casteel, 2021c), MeetinVR is designed for 10 (in the free version) to 33 (in the pro version) people to coordinate meetings in one of four virtual spaces from a variety of VR devices (Oculus Quest, Varjo, desktop VR, etc) with desktop video-calling support. MeetinVR uses a third party system, "ReadyPlayerMe" to create a stylized avatar from a photo of the user's choice, allowing for edits by the user. Alternatively, users can select preset avatars. Users can screen-share, share files, browse the internet, write sticky notes, draw in a 3D space, and collaborate using a shared whiteboard display.

Horizon Workrooms (Beta) . Currently in its BETA version (Casteel, 2021b; Facebook, n.d.), Horizon Workrooms is Facebook's recent solution to meeting within a virtual space. It supports up to 16 VR users, and up to 50 can join via desktop video-calling. The application is exclusively for the Oculus Quest 2 device due to hand and keyboard tracking requirements. It uses the inbuilt Oculus Avatar Creation system and adds dynamic facial animations to the avatar when the user speaks. Users can change the shape of the table to create three different VR spaces, but can only move from a sitting position at the table, or teleport to the whiteboard. Users have access to a Virtual Desktop, and can screen-share, share files, browse the internet, and collaborate using a shared whiteboard display. Writing in Horizon Workrooms involves a novel interaction whereby the controller's 'contact' with the table is used to emulate pen-on-paper.

Immersed. Founded in 2017 (*Immersed*, n.d.), Immersed allows users to collaborate in their pro and enterprise versions in seven different virtual environments through the use of whiteboards and virtual desktop integration. The application is designed for private meetings from four (in the pro version) to more than 12 users (in the enterprise version), with public virtual environments that support a larger number of users. The application runs for Oculus Quests, Desktop VR devices, and Phone VR (in Beta) and users customise their avatars through a third party application, "ReadyPlayerMe.", the same as described for MeetinVR. Unlike the other applications, Immersed did not support the use of sticky notes, 3D writing, or file sharing.

Glue . Glue, founded in 2017 (*Company - Glue*, n.d.; Casteel, 2021a), allows up to 10 users to meet within the choice of 10 (in the free version) to an unlimited number (in the pro version) of different virtual environments. Users are prompted to create their avatar upon loading into the application through the inbuilt avatar creation system. Users can write on a shared whiteboard, create sticky notes, write in 3D space, share files (including 3D models), browse the internet, and present on a dedicated large screen in each environment. A variety of platforms are supported such as the Oculus Quests, desktop VR systems, and desktop application support. Meeting sessions in Glue are limited to 30 minutes, however content persists in spite of this.

Table A1: Design Taxonomy for VR Meeting Applications

Category	Design Principles
Social Presence	- Embody participants with avatars - Use directional audio to identify speakers - Enable lip syncing and facial animations - Addressing the uncanny with familiar colleagues
Immersion	- Offer interactive tools (e.g., 3D pens) - Allow environment customization - Provide unrestricted movement within the space
Safety and Locomotion	- Introduce tools for personal safety - Provide predetermined spots for navigation - Avoid unintentional overlaps and intrusions
Onboarding	- Implement an intuitive UI design - Facilitate controls for teleportation, emotes, etc.
Familiar Spaces and Interactions	- Leverage familiar aesthetics in VR - Ensure high-fidelity interactions
Social Playthings	- Incorporate playful tools and animations - Design for play to foster team cohesion
Asymmetric Participation	- Ensure cross-platform compatibility - Prioritize asymmetric VR design
Collaborative Interaction	- Enable shared manipulation of objects - Allow multi-user file sharing - Offer shared whiteboards and note-taking tools - Integrate collaborative control for decision-making
Avatar Design	- Offer extensive customization options - Ensure avatars reflect user identity - Implement realistic movements and gestures
Etiquette and Behavior	- Define virtual personal space boundaries - Offer guides for VR body language - Implement mechanisms to handle distractions

Study 1: Participant information tables

ID	Gender Identity	Spatial.io	MeetinVR	HWB	Immersed	Glue	Focus Group
P1	Female	y	y	y	y	y	y
P2	Male	y	y	n	n	y	y
P3	Male	y	y	y	y	y	n
P4	Male	y	y	y	y	y	y
P5	Male	y	y	y	y	y	y
P6	Female	y	y	y	y	y	y
P7	Female	y	y	y	y	y	y
P8	Female	y	y	y	y	y	y
P9	Female	y	y	y	y	y	y
P10	Male	y	y	y	n	n	n
P11	Male	n	y	y	n	n	n
P12	Female	n	n	y	y	y	y
P13	Male	y	y	y	y	y	y
P14	Male	y	y	n	n	n	n
P15	Female	y	n	n	n	n	n
P16	Female	y	n	n	n	n	y

Table A2: Participant details in Study 1

ID	Gender Identity	Spatial.io-1	Spatial.io-2	HWB-1	HWB-2	Focus Group
P17	Female	y	y	y	y	y
P18	Female	y	y	y	n	y
P19	Female	y	y	y	y	y
P20	Male	y	y	y	y	y
P21	Female	y	y	y	y	y
P22	Male	y	y	y	y	y
P23	Male	y	y	y	y	y
P24	Male	y	y	y	y	y
P25	Male	y	y	y	y	y

Table A3: Participant details in Study 2

Appendix B

Further Example Quotes

In this section, we present some more example quotes related to the themes/sub-themes pre-sented in the findings section of the paper to provide further context to the themes.

ACTIVITY TYPES

Introductions/updates and paper discussion

"The paper review would have gone better, were the writing more legible. It was very pixelated for me, which caused eye-strain when reading. I can only imagine what the others in the room felt when faced with that problem, and it felt like an inhibitor to the feedback I subsequently received. The large visualisation of the text should have been more legible so that I could point at and highlight sections, such that when a discussion was started by one person, others in the room would be able to easily see the text, quickly read it, and add their thoughts." (P6, Study 1 survey, MeetinVR)

"During the paper review, I had some trouble working the interface as I had to 'reach' quite far to get the laser pointer to pop up. This may be something that could be distracting for a presenter as I struggle with the UI." (P5, Study 1 survey, HWB)

Presentations

"...watching the presentations worked well. With the ability to look up at the white-board or your own personal screen it felt much easier to digest the information." (P24, Study 2 focus group, HWB)

"Presenting felt much better than over zoom, having a large slide for everyone to see was very helpful." (P25, Study 2 focus group, Spatial.io)

"Well, you could share but [P18] would have to stop share and then you'd have to set up your computer, on the PowerPoint. It wasn't like interactable." (P22, Study 2 focus group, HWB)

"The control scheme of the app was intuitive, which makes the experience rather smooth. For example, we were able to perform a group presentation together just by uploading the file and interacting with it in the VR world." (P23, Study2 survey, Spatial.io)

"and the presenting in Horizon as well... like, you can't really see the screen, like when you're in the presenting stand position. So I can be like... not trying to.... trying to remember what was on the slide. So yeah, that's definitely where Spatial has a better working system." (P18, Study 2 focus group, HWB and Spatial.io)

Brainstorming

"The lack of indication of gaze made it feel strange when trying to make eye-contact (as though the other person was not looking back)." (P6, Study 1 survey, Spatial.io)

"Writing on the sticky notes was very useful as a quick and non-rigid resource that could be used for drawing, mathematical notations and diagram annotations, but it was very limited by the nature of VR, which struggles to provide enough feedback (e.g. a hard surface to write on), ultimately causing the writing to be messy and disorganised." (P19, Study 2 survey, Spatial.io)

"The pen works so well. The way that you can swap it around and write, just makes your handwriting looks like your real life handwriting." (P23, Study 2 focus group, HWB).

"Drawing was 2 strange and did not work as well as I expected. It was also a bit weird to have to draw on the desk in front of you which also had all my other stuff on it. I would have preferred to draw with the controller directly on the board if possible as I would have greater precision with a pointer device I think." (P3, Study 1 survey, HWB)

"Using the spawned in objects to help make points and be more emphatic during brainstorming really helped. Also exploring the note taking with different means (writing, typing, dictation) was interesting." (P18, Study 2 focus group, Spatial.io)

"..It was nice that you could load content from your own pc and save assets other people shared... It was hard to tell who was doing what, both in terms of who loaded what content and who was fiddling with other content." (P9, Study 1 survey, Spatial.io)

"...One of the biggest tools for teamwork was the ability to access my desktop." (P24, Study 2 focus group, HWB)

"The collaboration tools were helpful; having the sticky notes and presentation file was useful for tracking our ideas." (P19, Study 2 survey, Spatial.io)

PRESENCE AND IMMERSION

"My immersion felt like it was much less with this particular app, given the added ability to interact with the real world. Because I could see my computer interface within the virtual world, I felt the need for added features, like being able to see my keyboard, or my mug to reach out for coffee. This is the only time I've been sitting for the immersive meeting experience, with access to my desk. So I found myself often having to lift the headset either to move things so that I wouldn't accidentally knock them, or to see my keyboard, find my coffee mug, etc. Possibly as a result, but may not be linked, I experienced a good amount of discomfort from the headset which made it harder to contribute to the discussions as I was constantly adjusting it and my physical workspace." (P6, Study 1 survey, HWB)

"...So definitely having even a virtual space to put myself in, to get myself into a, 'hey, this is a learning activity,' or, 'this is a meeting...' getting myself into that mindset through a location is very helpful for me..." (P21, Study 2 focus group)

"...And I think, for me, since I haven't actually met any of you in person, it was quite interesting to be actually physically present in the environment. And so I think that, to me, VR seems like a very good tool for conferencing..." (P6, Study 1 focus group)

SOCIAL PRESENCE

"...I was very hyper aware of everyone in the room around me. Like the setting up with the presentation, it took me back to high school for a moment. I was like, 'oh, no! I'm in front of a bunch of people,' which is like immersive but it was also like... it gave me stage fright for a moment [laughs]." (P20, Study 2 focus group, HWB)

"The ability to interact with other people by clapping with haptics sold the notion that someone was 'next to you'" (P20, Study 2 survey, Spatial.io)

Avatars

"It kind of goes into that uncanny valley. Even though it's a real face, it doesn't look right. So the problem, I think there, is lack of options. So you have to take a picture of your face and that's it. And you have to get it right or it's bad. Whereas the Horizon, workrooms uses your Oculus avatar. I think that has a few more options but it's not perfect. Like it's kind of more like the Wii miis, which is kind of not referenced. Versus like The Sims, which is... you have a lot more... like a lot of options in The Sims, which would be better. And the cartoon style makes it a little bit harder to tell who's who but the moving of the mouth and stuff made it a lot easier. Like more interactable." (P19, Study 2 focus group, Spatial vs HWB)

"Well, Spatial is... it really felt like, kind of, real life because you're literally looking at people's real faces. And I'd have like, [P17] and [P23] and their smiley faces, because they'd like take a smiling photo. So they'd be looking around at me. And it's like I'm in the classroom and they're smiling at me. And so it's kind of like those little games you play in the classroom. So yeah, I think the realistic faces made that quite enjoyable socially" (P22, Study 2 focus group, Spatial.io)

"...you really feel like you're talking to the real person." (P22, Study 2 focus group, HWB) [on lipsyncing]

Non-verbal cues and proxemics

"Well, first of all, Zoom doesn't really have a world besides, you know, just the black background. It's not really... yeah, it's just... it's more about, you know, seeing the people's faces. And again, they're just flat images. Versus, when you're actually in, kind of... in the meeting areas in VR, it's more like being... more natural being in an actual room, where there are objects, you can look around, and it feels like, you know, like your whole life, you've been existing in a space rather than just online." (P19, Study 2 focus group)

TECHNICAL AND USABILITY CHALLENGES

Initial Set up

"Horizon... setting up on Horizon... like actually getting into the app was not fun, like the account problems. And to even open the app you have to... for Oculus anyway, you have to set up the desk and you must start it in hand tracking. It's not enough to have it enabled and to use a control. You actually have to start it using hands. And when you're actually in Horizon then you can go back to using controllers. That sort of annoying me." (P25, Study 2 focus group, HWB)

"Horizon Workrooms seemed quite well put together and a relatively seamless experience, both in VR and with the surrounding sign-in web application/software. Pairing an Oculus to the correct room worked fine and was much faster to set up than I expected." (P3, Study 1 survey, HWB)

"with immersive It was difficult to figure out the rooms because you only have like four people in a room at the most. And then I was not really too sure what we were doing with everyone else? But other than that, yeah, that's one of my main thoughts together." (P7, Study 1 focus group, Immersive)

"The process of signing up and accepting the workroom invite was a hassle though. After accepting the email invite, I had to make another account and log out of the one I had previously used for my VR headset in order to access the room. Aside from that, I think it serves well as a virtual space to work in with others." (P21, Study 2 survey, HWB)

Platforms

"Controls seem limited on PC version, but there are things I could do that I don't think others could, such as manipulating objects from across the room via mouse drag and drop." (P3, Study 1 survey, MeetinVR)

"...about Horizon, I do think that it's really designed for everyone to have their computer linked to the Oculus app and so if you haven't done that, then Horizon can become too restricting." (P21, Study 2 focus group, HWB)

"...I feel like there was so many problems. Not, not every app had every problem, but I think every app had at least one problem. So like, the one that irked me a bunch is that a lot of the apps were specifically designed for Oculus quest. But you couldn't run them on the Oculus quest one. Yeah. If that trend continues, and I must have the device of the year it is absolutely worthless to me. To buy a new headset every year?" (P4, Study 1 focus group)

Usability Issues

"Maybe [the VR apps] were just designed for smaller groups, because it seems to be common amongst all of them that once four more, four or more people were there, it go harder to collaborate." (P5, Study 1 focus group)

"There was many issues with people trying to touch and manipulate the same screen at one time, for example, I was attempting to resize the youtube video webpage and it would not follow my instructions properly. However this was fine when I was doing it on my own in the corner." (P10, Study 1 survey, Spatial.io)

"I felt like I couldn't do as much (i.e. interact with objects) and there wasn't as much visual/aural feedback when interacting with others." (P20, Study 2 survey, Spatial)

"...it's like good for professionalism but it was also a little annoying not being able to move around... I was using just like a kitchen chair. I didn't have a spinning office chair...if I wanted to get someone to speak I had to like really crane my neck and turn around and it was just really difficult. Like obviously that was sort of solved when you change the room into a layout like this one, rather than the rows. But it's still pretty annoying." (P24, Study 2 focus group, HW)

"...all the notes were left in the environment... there was no way for me to bring them back into the real world and reflect on them later if I wanted to" (P24, Study 2 focus group, Spatial.io)

FUTURE USE: TRADITIONAL VS VR MEETINGS

"...if you have like your camera turned off, it feels like...you're not actually there. Whereas like even if you're watching someone present in one of the VR apps, like you can turn to the person and High Five them, or something like that. Like you just feel like everyone can see you. Whereas like on Zoom, it's not until you're talking that you realise that people actually are aware of your presence." (P18, Study 2 focus group)

"... it's like, you can sit next to someone, you can look over them, when you can look across the room, versus Zoom is look from this window to this window to this window." (P19, Study 2 focus group)

"I do think that that there is space that these apps could get easier to join [similar to Zoom or Skype]. There's no reason why they can't, zoom does a great job with this. Just being able to hit join enter a code, the end. Very straightforward." (P4, Study 1 focus group)

"It[listening to the presentations] felt much more engaging that over something along the lines of zoom, being able to see the presenter, their hand gestures, etc." (P24, Study 2 survey, Spatial.io)

"...if I'm just sitting in front of a computer, looking at a screen, I get very distracted by the surroundings. But because it's in VR, you all like surrounded by that virtual environment, it's really easy to... you can interact with things in the environment easily. You can take notes if you want to or like, I guess, interact with people in Spatial as well. I found that a lot easier to stay on track in the VR meeting than Zoom." (P20, Study 2 focus group)

"I just... like I normally want to get stuff done fast... maybe in the future VR meetings would have more like functions to speed up the process" (P23, Study 2 focus group)

Appendix C

Screenshots from the Study 2 sessions

While we embedded multiple images from Study 1 in the main manuscript body, we did not embed any from Study 2 due to page limitations. Please see below some screenshots taken during the presentation and workshop sessions in Spatial.io and HWB.

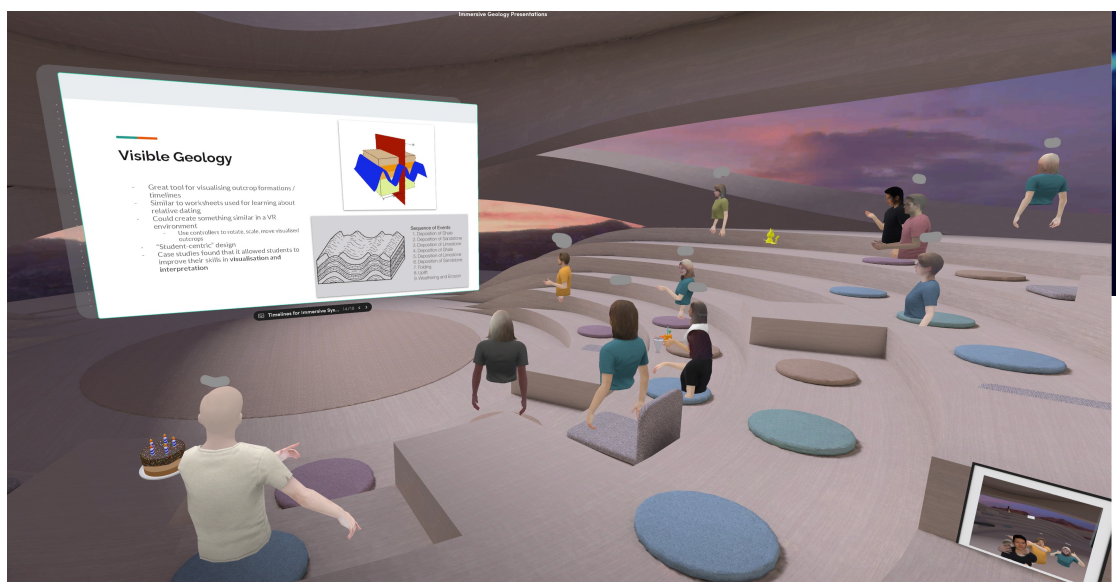


Figure C1. Presentation session in Spatial.io.



Figure C2. Presentation session in HWB.



Figure C3. Workshop session in Spatial.io. (Team 1 breakout room)



Figure C4. Workshop session in Spatial.io. (Team 2 breakout room)

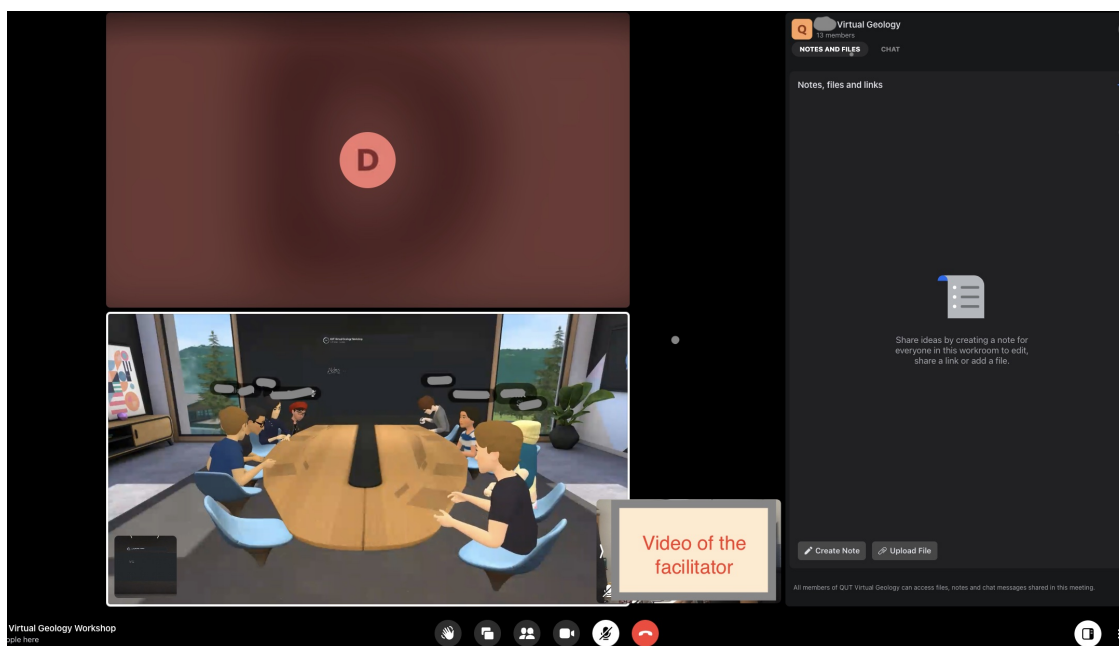


Figure C5. Workshop session in HWB in a conference room where the teams are presented with the project brief for the workshop. The screenshot is from the desktop view which facilitators used to joined the meeting due to technical difficulties. The lower right side shows [blocked for blind-review] the facilitator's video.)

Table D1: Social VR Workspace Features: Avatar and Annotation (*Pro Version; **Above Pro Version)

	Spatial.io	MeetinVR	Horizon Work-rooms (Beta)	Immersed	Glue
Avatar					
Appearance	3D-Realistic (from selfie)	Preset Avatars; Custom Selfie*	Custom-Select 3D Model	Custom-Select 3D Model	Custom-Select 3D Model
Movement; Mouth	Mouth; Head; Hands	Eyes; Arms; Head; Hands	Head; Arms; Hands	Head	Head; Hands; Mouth; Eyes; Eyebrows
Locomotion	Free teleport; Preset seats	Free teleport; Preset seats	Limited Views (2 locations)	Preset seats	Free teleport
Annotation					
3D Writing	Colour; Thickness; Displace; Duplicate	Thick-ness; Displace; Duplicate	Controller contact with desk to write; 4 colours	None	Colour; thickness
Post-it Notes	Pen colour; Post-it colour; Lock/pin; Displace; Duplicate; Type with virtual keyboard; or physical keyboard; Re-size/scaling	Post-it colour; Lock/pin; Displace; Duplicate; Type with virtual keyboard; Speech-to-text; Resize/scaling; Save; Export	None	None	Pen colour; Post-it colour; Pen thickness; Displace; Save; Export; Speech-to-text

Table D2: Social VR Workspace Features: Shared Resources and Conferencing (*Pro Version; **Above Pro Version)

	Spatial.io	MeetinVR	Horizon Work-rooms (Beta)	Immersed	Glue
Shared Resources					
Board Display	Attach Post-its, files and videos; Present	Whiteboard; available in some rooms; Write; hand-held mirrored board; Attach Post-its, files, and videos; Layout style; Save; Export	Write; 4 colours; attach images and files	Write; Shared*	Write
Screen Sharing	Yes	Yes (Screen-Cast)	Yes (Virtual Workspace)	Yes (Virtual Workspace)	No
File Sharing	Yes (MS Office files, PDF, 3D Models, Videos, Images)	Yes (Images, videos, PDFs)*	Yes	No	Yes (MS Office files, PDF, 3D models, Videos, Images)
Conferencing					
Browser Video-Calling	Yes (Webcam above avatar)	No	Yes	No	No
Audio	Mute/Un-mute Pop-up	Enclosed audio spaces	Spatial	-	Spatial
User-Limit	32	Yes (10 Free and *, 33**)	Yes (16 VR, up to 50 total)	Yes (1 Free; 4*; >12**)	10
Meeting Scheduling	No	Yes*	Yes (Works with Google and Outlook)	No	No

Table D3: Social VR Additional Features (*Pro Version; ** Above Pro Version)

	Spatial.io	MeetinVR	Horizon Work-rooms (Beta)	Immersed	Glue
Integrations	Office 365, Google Drive, Slack, Figma; OneDrive	OneDrive**	None	Twitter, Face-book, and Mail	Slack; Microsoft Office; Gmail; Google Drive (Docs, Sheets, Slides, Calendar); Jira; Miro; Mural; Salesforce; Trello
Computer Pair-Code	Yes (Needed to enter any room)	No	Yes (Needed to enter any room)	No	Yes
Virtual Workspace	No	No	Yes; Calibrated keyboard	Yes; Calibrated Keyboard	Yes
Web Browser	Yes	Yes (beta)	Yes (Virtual Desktop)	Yes (Virtual Desktop)	Yes
Premade Environments	7	4	None (Only different table shapes)	7	10
Custom Environments	Yes	No	No	No	Yes
Other	Avatar Selfie; Speech Captions*; Visible Speaker; Live Translation*	Mirror, Camera; Stick; pointer tool; actions; Persistent Content*; Analog Watch	Ranged Hand-tracking	-	Clock (Stopwatch and Timer); Camera; Laser-Pointer; Persistent Content; Gestures; Separate presentation display; Visible Speaker

Appendix E

References

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