Bridging Two Worlds:
Co-designing social spaces for autism from a neurodiversity perspective by exporting affordances of virtual worlds to physical spaces

By

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Abstract

From a neurodiversity perspective, autism is a form of human diversity. Neurodivergent people often find it challenging to meaningfully connect and interact with others in the physical world because they process information and connect with the world differently than many others. Virtual worlds have affordances that allow neurodivergent people to navigate, process information, and socially interact with others with much less effort than in the physical world, and thereby to thrive with their unique perceptual and cognitive styles. Through a series of iterative and inductive co-creation activities, three neurodivergent adults from different virtual autism communities and the author embarked on a journey to: (1) gain a better understanding of the unique affordances of the virtual world that allow neurodivergent people to express their thoughts and connect meaningfully with others; and (2) co-design with neurodivergent adults social spaces in the physical world that incorporate these affordances. A virtual reality (VR) space and an augmented reality (AR) application are the results.

Acknowledgement

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I finally wish to thank my family, friends and colleagues for their support and encouragement throughout the study.

Dedication

Being a teenager is tough. All teenagers must navigate through the turbulent period of a string of conflicts at home and school on a biologically driven emotional rollercoaster putting them at a higher risk of precarious behaviours (Steinberg, 2004, 2007). Things get even more complicated when you are a neurodivergent teenager. Being neurodivergent means that you process information and connect with others and the world differently than the majority of your peers, making it even harder to "fit in" in this vast world (Baron-Cohen, 2008; Murray, 2005; Nolan & McBride, 2015). It was for them this study was initially launched. Although the final design prototype of this study is for both neurodivergent teenagers and adults, I would like to dedicate this study to neurodivergent teens who are finding their places in our predominantly neurotypical world.

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Introduction

Autism is more commonly known as autism spectrum disorder (ASD) and in recent years it has become one of the most publicized neurodevelopmental disorders (Deonandan, Liu, Kolisnyk, & Konkle, 2016). Within the deficit-focused medical model, autism is characterized by social-communication challenges and repetitive/restricted interests and behaviour patterns (American Psychiatric Association, 2013). In recent years, however, many self-advocates joined together to drive the neurodiversity movement to change this publicized view of autism from that of a disease in need of cure to a form of diversity among humans (Broderick & Ne'eman, 2008; Robertson, 2009). The neurodiversity perspective suggests that challenges experienced by people with traits of autism, dyslexia, and other forms of neurodiversity are design issues rather than medical issues: their current environment is not designed to embrace their unique styles of communicating and connecting with others. The current study is rooted in this neurodiversity perspective. It is out of respect for this perspective and the wishes of my study's co-creators that I chose to use "identity-first" language (i.e., autistic teen) rather than "person-first" language (i.e., teen with autism) throughout this paper (Kenny et al., 2016). Further, the term "neurodivergent" will henceforth be used to refer to those persons who specifically identify with traits of autism.

Interestingly, the neurodiversity movement evolved with the rise of internet-based virtual communities along with other disability rights movements (Kras, 2009). In the virtual world, neurodivergent self-advocates were able to come together and share with the world their views on autism and their experiences despite their reported challenges with sociality in the physical world. The explosion of uses of social media, blogs, and discussion forums (Nguyen, Duong, Venkatesh, & Phung, 2015; Nguyen, Phung, & Venkatesh, 2013) suggests that there are certain design features that are unique to the virtual world that make it easier for neurodivergent people to express their thoughts and connect meaningfully with others. These design features in an environment that make particular sets of actions possible, for instance sharing ideas and thoughts through a social media post, are referred to as affordances (Gaver, 1991). Affordances emerge between unique capabilities of individual and design of environment.

I embarked on this study with two goals in mind: (1) gain a better understanding of the unique affordances of the virtual world that allow neurodivergent people to express their thoughts and connect meaningfully with others, and (2) co-design with neurodivergent adults social spaces in the physical world that incorporate these affordances.

Through a series of co-creation activities, we were able to identify four affordances of the virtual world: safe space to explore and be themselves; alternate ways to create and understand meanings; object-centered sociality; and moderation. The final design prototypes are results of our effort to export these affordances into social spaces in the physical world. It is important to note that the purpose of the final prototypes—a Virtual Reality (VR) space and an Augmented Reality (AR) application— was to demonstrate our findings rather than to build testable technologies. Future research should focus on testing and evaluating both of our design ideas.

Autism and Virtual World

Compared to their neurotypical peers, and starting early in their lives, neurodivergent individuals appear disengaged and disinterested in social activities and peers in the physical world (Kasari, Locke, Gulsrud, & Rotheram-Fuller, 2011). This pattern continues into the teenage years (Humphrey & Symes, 2011). However, the absence of social interactions or connections does not mean a lack of desire to connect socially and meaningfully with others. More and more, self-advocates and researchers report that neurodivergent individuals indeed do feel a great sense of loneliness and a desire to make and keep friends (Ariel & Naseef, 2006; Lasgaard, Nielsen, Eriksen, & Goossens, 2010; Murray, 2005).

Huge gaps between how neurodivergent people perceive and act on the world and how our physical world is organized are much to blame for their challenges to meaningfully connect with others. Our physical world comprises not only objects that inhabit space but also people who act with, on, and alongside these objects and each other. Social interactions are composed of two or more people and a series of social actions. For actions to be considered "social," it requires not only a person producing an action (with or without an object) with the intention to be social but, also, that the other person or persons who are present can recognize the shape and character of what is occurring and interpret and act upon its meaning accordingly (Goodwin, 2000). For example, the action of waving itself is not social if I wave to a barren wall in an empty room. Waving becomes a social action only when there is another person in the room who sees it and interprets it as an attempt to greet another person. However, it is also possible that it was not intended to be a social action even though it was interpreted as such.

Perceptual and cognitive differences in neurodivergent people create a mismatch between them and the physical world. Specifically, neurodivergent people may interpret social actions and other

aspects of the physical world differently than others and produce actions that may be interpreted by others in ways the neurodivergent people had not intended. The virtual world, on the other hand, has certain affordances to remedy this mismatch and allow neurodivergent people to connect with others socially.

Our social interactions often rely heavily on complex combinations of speech and body language that happen in quick succession. In order to accurately interpret the meaning and intentions of another person's actions, one requires the ability to piece together bits of contextual information. Neurodivergent people tend to focus on some of these bits in great detail. However, shifting their attention away from these bits and piecing them together in a social context tends to be difficult (Koldewyn, Jiang, Weigelt, & Kanwisher, 2013). In the virtual world, we are able to communicate and interact with means other than speech such as texts, images, audio-visual clips, and files that are less prone to quick changes.

Sensory challenges experienced by neurodivergent people add to the difficulties navigating and making sense of the physical world (Leekam, Nieto, Libby, Wing, & Gould, 2007). Both aversive and desirable sensory stimuli such as certain scents or textures can affect your experience of the physical world. Aversive stimuli especially can impact neurodivergent people's abilities to attend to important verbal and nonverbal information (Orekhova & Stroganova, 2014). The virtual world is free of these sensory distractions that are present in the physical world such as background noise, flickering light, or an unpleasant room temperature.

In addition, in the virtual world social interactions between people are mediated through shared social objects such as pictures, hyperlinks, news items, and game objects (Engeström, 2005;

Warburton, 2009). These objects serve to attract the attention of people who share the same interests, spark conversations, and help build connections between them.

All of these features of the virtual world create a space in which neurodivergent people can thrive because they are able to use their perceptual and cognitive abilities to process information and engage with others with much less effort than in the physical world. The virtual world therefore effectively provides visibility, a voice, and an alternative means of communication for those who are socially isolated and stigmatized in the physical world (Danilovic, 2009).

Autcraft[1] is one such community. Autcraft is a Minecraft virtual world created especially for neurodivergent children and youth and their allies. Minecraft is an open-ended virtual world where players are allowed to experiment and design their own environment (Cipollone, Schifter, & Moffat, 2014). With the available tools, they are free to create, destroy, recreate, and explore. This freedom makes Minecraft a perfect sandbox for neurodivergent children and youth to create an environment that fits them rather than trying to fit into an existing environment. Recent ethnographic research revealed that players in Autcraft indeed used tools to create social and sensory experiences that suited their needs: Autcraft players had positive and meaningful social interactions with other players through creation projects, mini-games, and events, thus demonstrating their engagement in object-centred sociality (Ringland, Wolf, Boyd, Baldwin, & Hayes, 2016; Ringland, Wolf, Faucett, Dombrowski, & Hayes, 2016).

Minecraft's players extend their acts of creation beyond the virtual world into the physical world through the creation of artworks and 3D printed materials (Nguyen, 2016; Wadley, Schutt, & Ng, 2016). Autcraft's players also extend their creations and interactions outside of Autcraft across various virtual platforms such as a website forum, YouTube, Twitch, Twitter, and Facebook

[1] https://www.autcraft.com/

(Ringland, Wolf, Faucett, et al., 2016). However, whether the benefits of social connections and freedom to rearrange their environments extend beyond the virtual world remains unclear.

The Lab, a project based in Australia, was born to extend some of these social benefits of the virtual world into the physical world (Schutt, Staubli, & Rizzo, 2015). The Lab is a network of after school social spaces for neurodivergent teens. Leveraging on neurodivergent teens' special interest in technology, teens are free to explore various projects, such as building websites, experimenting with 3D printing, and playing games (Schutt et al., 2015). Through these activities, teens are able to craft their own computer-mediated forms of expression. Like Autcraft, The Lab promotes object-centered sociality— teens with each other and teens with mentors, all of whom support through their projects the learning of technical skills (Rizzo, Schutt, & Linegar, 2012). In addition, teens are able to communicate and share their experience with each other via their computers even when they are present in the same physical space.

There is still much to learn about how to use unique affordances of the virtual world and other technologies to help neurodivergent people navigate and meaningfully connect with others in the physical world. New technologies, such as VR and AR, give us ways to manipulate and augment how we experience our environment, providing even greater possibilities to reimagine how neurodivergent individuals navigate the social world and build connections with others. The objective of this study was to accomplish just that.

Autism and Technology Design

While no two people ever experience the world in exactly the same way, many neurodivergent people have shared similar stories, through their participation in research, books, blogs, and social media, of difficulties with making and keeping friends, managing various social situations, coping with changes in routines, and other sensory challenges. It is unsurprising, then, that the research

community's interests in developing technologies to address the needs of neurodivergent people and the people who support them also grew rapidly over the last decade (Aresti-Bartolome & Garcia-Zapirain, 2014) as the prevalence of autism shot up from 1 in 150 children in the year 2000 to 1 in 59 children in the year 2015 (CDC, 2018).

With the advancement of technology, the possibilities are vast—technology can help to create controllable and predictable environments for practicing new skills; offer multisensory stimulation or modulation; and provide alternate means of communication (Aresti-Bartolome & Garcia-Zapirain, 2014). However, the research and development of technologies for autism most often do not include the voices of neurodivergent people or even address the needs prioritized by them.

Aresti-Bartolome and Garcia-Zapirain (2014) illustrate the landscape of technologies for autism through their thorough review of the articles published between 2004 and 2014. In the review, the authors discovered that most of these technologies were developed for treatment purposes, especially to teach children specific communication and social skills. Most of them, regardless of type (e.g., virtual reality, applications, telehealth tools, or robots), were developed—without the involvement of individuals—for generic rather than individual needs, making them neither usable nor generalizable to various individuals.

To be fair though, including perspectives of users in developing technologies is a relatively new phenomenon and is still emerging across the research (Coleman, Clarkson, & Cassim, 2016). More recent projects, such as the ASCmeI.T. project in the United Kingdom, show the researchers' efforts to put such inclusive practice in action (Parsons et al., 2016). The ASCmeI.T. project provides a platform through which people from the autism community can share their day-to-day challenges

and ideas for new technology to help with the challenges. Through this platform, individuals are involved from the very start of new technology development.

The purpose of the current study is not to create technology-mediated treatment or technology for treatment delivery. Rooted in the neurodiversity perspective, the current study aims to employ inclusive methodologies and to design together with neurodivergent people, environments and tools for them to navigate and connect with others in the physical world rather than to "fix" or "change" them. Therefore, one of the contributions of the current study is to this emergent field of inclusive design of technology with neurodivergent people.

Methodology

The current study adopted the participatory design methodology to ensure the inclusion of neurodivergent people in the design process. Originated in Scandinavia in the early 1970s and 1980s, participatory design emerged to empower workers by involving them in determining the shape and scope of new technologies introduced into their workplace (Spinuzzi, 2005). The methodology promotes the spirit of designing with people rather than for people, which is especially empowering for neurodivergent people whose voices and perspectives are often underrepresented in the design process, as mentioned in the previous section.

Participatory design is rooted in the constructivist paradigm in that it sees knowledge making as occurring through the interaction between people, actions, and artifacts. Within this paradigm, researchers and participants work together to bridge participants' lived knowledge and experience, and researchers' "analytical knowledge" (Ehn & Kyng, 1992; Ehn, 1988). In order to do so, participatory design emphasizes co-research and co-creation where participants are actively involved in deciding on research objective, process, and evaluation.

Due to its iterative nature, participatory design often tends to be quite flexible. As the research unfolds, researchers need to continue to learn and adapt based on ideas and artifacts co-created with participants. However, there are three basic stages that are present in almost all participatory design research (Spinuzzi, 2005):

- **Stage 1** Initial exploration: In this stage, designers meet with users to get to know each other and start exploring the problem space.
- **Stage 2** Discovery processes: In this stage, designers and users use various methods to understand participants' goals and values in order to agree on the desired outcome of the project.
- **Stage 3** Prototyping: In this stage, designers and users iteratively shape artifacts towards the desired outcome.

The methods and tools used in the participatory design research are selected with careful consideration of the participants and tend to be open-ended. The methods and tools used in this study are described in a later section.

Participants

Participants of this study were recruited as co-creators to participate in a series of co-creation activities to (1) gain a better understanding of these unique affordances of the virtual world that allowed them to express their thoughts and connect meaningfully with others; and (2) co-design social spaces in the physical world by exporting these affordances. It is important to note that initially the focus of the study was neurodivergent teenagers. However, as our artifacts evolved, the focus was widened to include adults.

Co-creators were required to be adults who were (1) 18 years of age or older; (2) self-identified with a neurodivergent phenotype such as autism; and (3) currently participating in virtual autism communities.

To recruit co-creators of the study, I began by contacting administrators of active virtual autism communities to obtain their permission to publish or distribute the recruitment post. These communities included self-advocacy groups' websites, forum-based communities, Facebook groups, Reddit, Twitter, and blogs. Four people reached out for more information after seeing the recruitment post. Out of these four, three completed and returned consent forms.

Three adults—John, Aaron, and Tammy—who were currently participating in virtual autism communities were recruited as co-creators of the study. John is not his real name as he wished his identity to remain confidential. From the beginning of the study, Aaron and Tammy gave their consent to be identified with their own names. All three co-creators identified themselves as neurodivergent. John is from a community based on Reddit, an online discussion website; Aaron is from a Facebook group; and Tammy has her own blog and participates in Twitter conversations on autism. All three of them participate in other types of online communities focused on their special interests such as robotics, gaming, and crocheting.

Upon the completion of the co-creation activities, co-creators were thanked for their time and contribution with an electronic gift card (value of 50 Canadian dollars) for the store of their choice for their time and contribution. The award of electronic gift cards was not mentioned in the recruitment post. Only those who contacted me for more information and received the consent form, which included the information about the gift card, were aware of this award.

Setting

All the conversations and co-creation activities with the co-creators took place between December 2017 and March 2018. They took place online using Skype[2], with the exception of John who used a landline as he was no longer using Skype. Each co-creator met with me six times for an hour each time. Due to the timing of the recruitment and scheduling conflicts, only one of the sessions had two co-creators attending at the same time. All the conversations were recorded for the data collection and analysis purses as described in later sections. Our interactions relied heavily on virtual collaboration tools such as the screen share function of Skype, Google Docs[3], Google Slides[4], Google Hangouts[5], Stormboard[6], and Slack[7] to substitute for physical collaboration tools such as paper worksheets, Post-it notes, chart papers, a whiteboard and markers.

Co-creation Activities

Participatory design methods, here referred to as co-creation activities, can be grouped by the three stages of participatory design as well. Each session, participants engaged in activities to explore, discover, and create new ideas (Ehn and Kyng, 1991). Table 1 summarizes activities used for each co-creation session and the resulting artifacts.

Stage 1 Initial exploration: In this stage, the ways in which neurodivergent people navigate and interact in the virtual and physical worlds were explored through a literature review and interviews. The interviews were exploratory in nature and served two purposes. The first purpose of the interviews was to identify affordances of the virtual world from the participants/co-creators' own perspectives. To this end the interviews focused in on these specific topics: why the co-

[2] https://www.skype.com/en/
[3] https://docs.google.com
[4] https://docs.google.com/presentation
[5] https://hangouts.google.com/
[6] https://stormboard.com/
[7] https://slack.com/

creators participated in their various communities; advantages and disadvantages of the virtual community for building social connections and the quality of these connections; how these connections influenced their life in the physical world; how these connections are different from those in the physical world; and ideas for improvement. The second purpose of the interviews was to ask questions that would prompt the exploration of ideas about bridging virtual and physical worlds.

Stage 2 Discovery processes: Following the initial exploration, ideas gathered during the exploration stage were discussed in more detail and organized to gain deeper understanding of them and discover design opportunities. Analogous inspirations helped co-creators to shift their focus to another context (i.e., communities for their special interests rather than autism) to discover unexpected insights for the current study.

Stage 3 Prototyping: For prototyping, co-creators explored and gave feedback on existing prototype ideas and concepts. Such activity also provided opportunities for them to generate new ideas for our own prototype. In other activities, they tested out and modified low fidelity prototypes, created a persona and journey map, and participated in simulation of the prototype to put together insights from the first two stages.

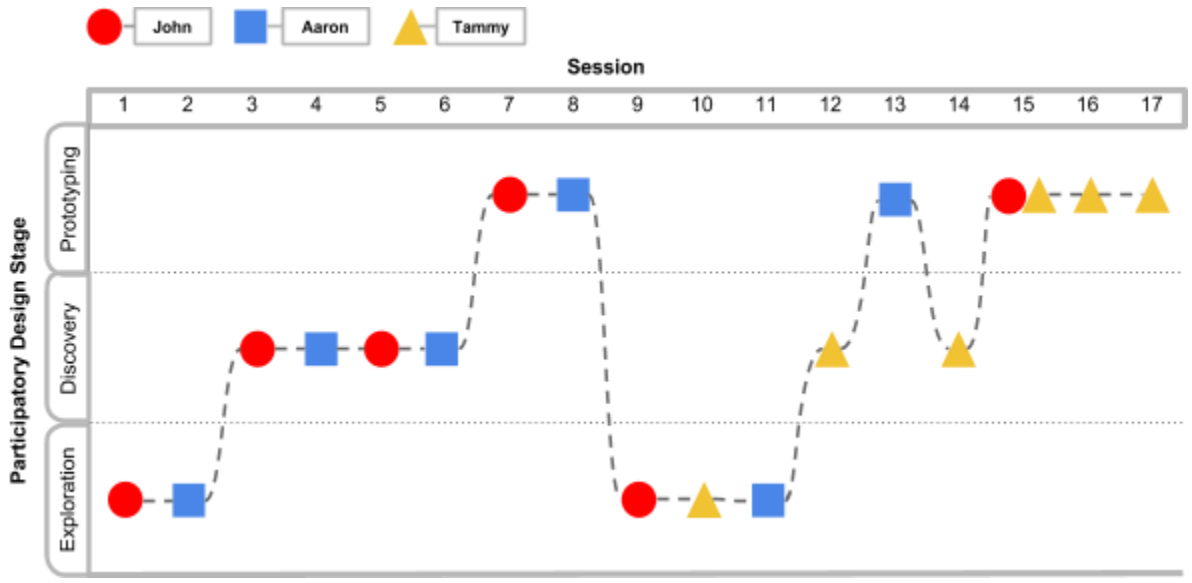
As in many of participatory design studies, the current study was iterative and inductive in nature which allowed co-creators and myself freedom to explore design possibilities with various semi-structured and open-ended activities. As a result, it was necessary for the three stages of activities to be repeated several times and in varying order as illustrated in Figure 1 described in the co-creation activities section.

Table 1 Summary of co-creation activities and artifacts

Session(s)	Activities	Artifact(s)
1 & 2	Semi-structured Interview: In separate sessions, John and Aaron were asked a series of open-ended questions to gain insights into their experience in virtual autism community.	Main findings were organized on Stormboard, a virtual whiteboard, for the following sessions.
3 & 4	Organizing ideas: In separate sessions, John and Aaron reviewed main findings from interviews on the Stormboard and clustered them into categories. They were able to add any other related ideas to the board.	Stormboard with findings further organized by John and Aaron.
5 & 6	Analogous inspiration: In separate sessions, John and Aaron were asked to share their special interests and what virtual and physical gathering of people who share the special interests may look like.	URLs for special interest groups and screenshots of useful features.
7 & 8	Concept feedback: In separate sessions, John and Aaron were provided with a wireframe of online community that was developed prior to the study for feedback and ideas. In the second half of the session, they reviewed a list of AR app ideas for autism.	Wireframes and apps list with annotations.
9 & 11	Discussion: In open-ended dialogues, John, Aaron and I discussed, for additional ideas for a prototype, challenges with living a neurodivergent life.	A low-fidelity prototype using Google Slides.
10	Semi-structured Interview with Tammy: same as sessions 1 & 2.	Same as sessions 1 & 2.
12	Concept feedback with Tammy: same as sessions 7 & 8.	Same as sessions 7 & 8.
13	Concept feedback: Aaron tested out the prototype, which is a cumulative artifact from the end of session 11. He added new features to the prototype.	Updated prototype from session 11.
14	Analogous inspiration: same as session 5 & 6.	Same as session 5 & 6.
15	Simulation: Using Google hangout, we simulated the use of the prototype.	Updated prototype from session 13.

16	Creating a persona & a journey map: In this activity, Tammy was asked to create a persona who would use the prototype we have created thus far. The persona was used to create a journey map with different touch points to gain further insights into features that may need improvement.	A persona and journey map.
17	Simulation: Tammy used the persona she created in the previous session to "walk through" a scenario with the prototype.	Updated prototype from session 15.

Figure 1 The journey of co-creators through three stages of participatory design across co-creation sessions.



Data Collection

As previously mentioned, all of the interactions with the co-creators during co-creation activities were captured in the audio recordings and digital artifacts produced through the virtual collaboration tools. The researcher's notes were also used in the qualitative data analysis.

Data Analysis

At the end of each session, I examined my own notes and transcript of the session. I marked important pieces and added descriptive names or "codes" to them (Gray, 2013). This coding process helped determine the focus of the next session. The notes and codes were also reviewed at the weekly meetings with the primary advisor of the study. Using the iterative and inductive approach, themes emerged from further coding of the accumulated data and collapsing some of the codes into broader categories. These themes reflected some of the affordances of the virtual world that allowed co-creators to explore and connect meaningfully with others.

Affordances of the Virtual World

Through our time together, co-creators and I identified affordances of the virtual world that keep them participating and connecting with others in meaningful ways in their respective autism communities. Our findings verified and expanded on some of the previous findings in the literature and that were discussed earlier in this paper. Affordances of the virtual world identified throughout the study were as follows: safe space to explore and be themselves; alternate ways to create and understand meanings; object-centered sociality; and moderation. These core features began to emerge throughout the earlier conversations during our time together, starting with the semi-structured interview (see Appendix A). As we progressed through the co-creation activities, they began to take clearer forms.

1. Safe space to explore and be themselves

One of the best features of the virtual world revealed itself to be the ability to explore without being seen or judged. As a visitor or a new member, you are able to visit different areas of the community by clicking around and reading along threads of interactions to decide whether it is the right community for you or not. As John shared:

> *There's no greeter at the door and there's no one inviting you in, there's no ceremony. You kind of see what happens like experimental approach. You can try to ask questions. A lot of people sit and read for a while. Then they gather courage and ask a question. Usually people who respond are respectful. That builds trust. That's what makes it all work. (John; session 1)*

Even when you are actively interacting, there is a sense of invisibility because your true identity is often hidden behind usernames and profile photos or avatars. Online, you can choose how much about yourself to share or how to present yourself. This sense of invisibility alone helps to ease the awkwardness or anxiety of interacting with others online. It allows members to feel safe and free to be themselves and express their feelings and share their life stories. In a physical space, there is often a sense of vulnerability. Not simply because you can be seen, but because of the history of being met with judgement and criticism about acting and talking "weirdly" or "awkwardly"—because of the history of feeling like you don't fit in or you can't connect with others. Tammy shared:

> *I think the thing about the online world [Twitter and blog] is that those people don't know me as me. I don't say these things on Facebook because those people know me. They are my family and people in my community and stuff. So I don't engage in the same way online with those people. Because those people don't understand and won't understand because I spent a lot of time trying to fit in and getting along with people. But i wasn't necessary myself with them. whereas when you're online, people that you found that are out there that are all like you then you can be yourself. (Tammy; session 10)*

Another advantage of virtual space is that it is free of many painful sensory stimuli such as certain sounds and lighting that are rampant in the physical world. The physical world can seem like a sensory minefield for those with sensitivities to certain sensory stimuli. Being able to process and coordinate various senses helps with motor planning, or "praxis," which is required for us to respond or act appropriately in various situations. When it's affected, it can be challenging to manage successfully in the physical world which can in turn impact social interactions with others. For instance, Aaron and Tammy shared:

> *For us, looking at light is like looking at the sun. For us, one of things that we will often talk about is how we are always tired. And it's because our senses are so to the max (Aaron; session 3).*

> *Chair is so uncomfortable and room is cold. I just spend whole time staring out the window. It's in this community centre that's right by the entrance. You can hear door open and close, hear people come in, the squash court, car zipping by here. It's so distracting. I don't enjoy it. (Tammy; session 14)*

For those who may have had experience with others in their environment negatively reacting to their "inappropriate" actions or responses, they are likely to be more self-aware and avoidant of social situations in the physical world. In the virtual world, they are not only able to remain invisible but also have control over certain sensory stimuli. For instance, you can adjust the brightness of the screen, change the volume, or move with your device, such as a phone or a laptop, which connects you to the virtual world, to a physical space where you can set the temperature, noise level, and brightness to your liking.

The virtual world, especially autism community spaces, therefore provides a safe space where people can be themselves, expressing their thoughts and sharing their life stories when they feel ready to do so. It also creates a liminal space between their day-to-day realities and a perfect world where neurodivergent people have full control over their environment and everyone understands how they experience the world. In this space, they get to leave behind their everyday selves and struggles and experiment with their identity, social interactions, and social norms.

2. Alternate ways to create and understand meanings

The virtual world provides co-creators alternate ways to create and understand meanings, including intended uses of the space and the intentions of others. This is made possible through concrete cues and information, and alternate and asynchronous forms of communication that are particular to the virtual world.

In the virtual world there are many concrete and visual cues and information embedded within the space that help co-creators navigate and interact with others. There are navigation menus and hyperlinks to help them understand how the space is organized and where to find what they are looking for. Little signs that indicate whether a person is online, offline, or busy makes it clear to the others whether it's a good time to chat or not. Threads of conversations are made up of posts created by more than two people; the threads appear in such a way that they visually organize the beginning and ending of each conversational exchange, and give you some guidance on how to join in. Re-reading threads also provides an "aid" or help to investigate and reflect when things go wrong. In some communities, rules are clearly defined and posted to let members know up front how to behave and which behaviours are not acceptable. These characteristics make the organization and interactions within the virtual world predictable and easy to understand.

As mentioned previously, the virtual world allows people to communicate through texts, audio/visual recordings or chat, and other file formats such as 3D printing files. This is unlike our physical world, where we rely heavily on speech and gestures. This was an especially helpful feature for the co-creators. The real benefit of using alternate communication such as texts turned out to be the time delay. When typing a post or replying to a post, it allows them to take time to process, collect their thoughts, and put them into words. They are able to express their thoughts uninterrupted, and without having to exert energy to check for listeners' facial cues and gestures of approval, disapproval, boredom, annoyance, or confusion. John shared how asynchronous communication using text helps him to understand meaning behind words:

> *I can only speak for myself but I've seen some other people mentioning that for us the real time conversations don't give enough time to process or think about what we want to say. So asynchronous forms of communication like text on Reddit, email or Facebook give us that time we need to think about the words, formulate our response and say what we want to say. In the real time situation, we might not be able to do that quick enough. (John; session 1)*

Similarly, Aaron shared the benefit of a still photo when trying to learn about and understand another person:

> *You learn a lot about a person in a photo. If I am looking at you, you are moving and you laugh, cry, is change from second to second. But if you look at a photo stays the same. Some able to look at it longer and because I can look at it longer I can understand more about that person. I can understand more about what they're experiencing in the moment I can tell you more about that emotions they are feeling at the time. I don't like eye contact but I can understand the person better. (Aaron; session 4)*

All these alternate ways to create and understand meanings help co-creators to have more positive and effortless interactions with others in the virtual world than the physical world.

3. Object-Centered Sociality

The virtual world promotes object-centered sociality which means that social interactions are mediated through social objects. Social objects used in autism communities, in which co-creators participate, are predominantly discussion or blog posts and pictures. A virtual autism community is a network of people who are connected by these shared objects using technology-mediated communication forms.

In addition, virtual autism communities often have a clear purpose—to learn about autism and connect with others who think and experience life in similar ways. Everyone, even silent observers, is there for a similar purpose. Anyone who participates is motivated to do so and do so voluntarily. Since the conversation topic is clearly defined—autism—there is no awkwardness or stress from struggling to come up with what to talk about, which may be the case with in-person conversations. The conversations and interactions flow and flourish within the structured space and available modes of communication which guide how to participate and what to contribute. For instance, when one member creates a post asking a question, another member reciprocates by creating another post with an answer. Co-creators also share their knowledge and experience with others in the virtual world through creating web pages and blog posts:

> *I'm working on - It's an Asperger's self-treatment wiki. It is something I put together. I have been doing all the research myself and I figured since I'm doing it anyway I might as well have it all put together in a document. So next guy who comes along is like 'I'm in the same boat. Oh well, here, this guy did all the research.' Maybe they'll do a little more research and find something to add to it. (John session 9)*

> *It's been neat, because I've been able to share. If I read something special from someone else, I feel like I want to give back in a way. I don't want to just consume all the good stuff that everyone else has put out there. I want to contribute to that. I have a unique story. It's similar but no one has lived my life, my issues. But other people can probably relate. (Tammy session 10)*

Through these processes of creating and sharing, co-creators not only gained positive interactions with others but also gained better understanding of themselves and reconstructed their identities as neurodivergent adults. John shared:

> *We get rejections everywhere we go and people say to us, 'you can't say that because it's rude, you can't say that way.' It's the constant negative feedback cycle. To break that cycle and get positive feedback and self-esteem, that's getting their identity back and start to have more happiness and self-concept. (John; session 1)*

4. Moderation

The last important feature that was identified as invaluable for successful participation and interactions in the virtual world was moderation.

Human interactions are complex and, even in an ideal virtual space with the first three core features, there are many ways in which things can go wrong and conflicts arise. For instance, members may break rules and share inappropriate content. Or a post can be misunderstood and lead to a quick cascade of angry and hurtful comments. In the virtual world, moderators can step in to help restore the order when rules are broken and conflicts arise. The importance of moderation and good moderators in virtual communities was one of the first topics John brought up in our earlier exploration.

> *Why people join online communities? One of these is because they have moderation. They don't get abused in there. They don't get treated bad. When there is misunderstanding it gets taken care of. These are reasons why they join online communities. (John; session 3)*

Moderators maintain the order of community by enforcing rules and mediating any conflicts that arise between members. They are also mentors who can guide members through difficult situations online, using them as teaching opportunities for future interactions. For instance, Aaron shared:

> *It [having moderators] kind of helps socially speaking because if you do something wrong like people can say hey you know this was not okay or they can help guide you to understand why that was not okay or they can help explain you the rule - like you don't call a gal certain words because those words are always considered disrespectful. (Aaron; session 6)*

In the physical world, our interactions are often ephemeral. Words we speak and actions we take disappear as soon as they are spoken and taken. When a moderator steps into a conflict situation in the physical world, there is not much proof to clearly understand exactly what has happened other than oral stories stated by each side. In the virtual world, words and actions are more permanent. A moderator can follow through threads of conversations to assess what has happened and intervene accordingly, such as giving a warning to the person at fault and/or removing the inappropriate content.

In a good virtual community, moderators are people, either neurodivergent or neurotypical, who understand and embrace neurodiversity and the challenges neurodivergent people may experience daily and across their lifespan. They ensure that the community remains a safe space where members can be themselves, experiment with social interactions with others, and learn from their mistakes. John and Tammy shared who they thought would make good moderators:

> *You would have to have older people who understood what the goal of the group is. I think you have to understand way kids think—so they are not trying to steer them in the way that's not realistic I guess if it's for neurodivergent kids, you want similar moderators but they would not have to have PhD. (Tammy; session 12)*

> *You need a person who can see both sides. Like if they are neurotypical and moderator, they are usually ones who are married to someone with Asperger's—makes good person to have both sides but still represent neurotypical perspective. On the Asperger's side and they are married to neurotypical person, and they can represent the Asperger's side but also understands the neurotypical side. [...] And also, in our community there's a lot of people who have been victimized at some point, either by rapists or bullies or siblings or the system in general. And there's a lot of that subjects that can come up. If you are not ready to handle whole group then you may not make a good moderator. (John; session 3)*

The affordances of the virtual world identified here—safe space to explore and be themselves; alternate ways to create and understand meanings; object-centered sociality; and moderation—allowed co-creators to connect and interact with others in a positive and socially meaningful manner.

Co-creators shared that the benefits of their positive experience had extended beyond the virtual world and into their physical world. Specifically, they shared that learning about autism from others led to a better understanding of themselves and had a positive impact on their daily life and relationships with their friends and family. However, they shared that these interactions were often confined in the virtual world. While they shared that it would be hard to replace in-person interactions in the physical world with the virtual world, they voiced their preference for virtual interactions because the physical world does not have the same affordances. This made it clear that there is indeed a gap between the virtual and physical worlds that could be bridged by exporting the affordances of the virtual world into the physical world.

Bridging Two Worlds (B2W)

Through multiple iterations of prototyping, the co-creators and I attempted to bridge the virtual and physical worlds by exporting the affordances of the virtual world into the physical world. Our design goal was to enable users to explore a social space in the physical world and connect with others in the same space. A VR space and an augmented reality AR application are the results.

With a VR camera, it is relatively easy to create a real-time three-dimensional rendering of a physical space and allow people to have telepresence—immersive access to the physical world without physically being there (Steuer, 1992). Use of the VR technology allows us to create a portal through which people can experience and participate in activities that are taking places in the physical world. AR technology, on the other hand, can add or remove audio and visual elements to and from the physical world therefore "augmenting" the experience of the physical world (Azuma, 1997). AR technology therefore allows users to enter a physical space and customize their experience of it without physically rearranging or modifying the elements within it.

The VR space is a space between online and offline spaces, and transcends geographical barriers. It allows users to explore the physical space without having to be there and without being seen. Users who are joining the VR space can choose to explore the space without being seen by others. VR rendering of physical space provides users with a 360-degree view of the space as well as the control of the view. They are able to watch and choose, when they are ready, when and how to participate. Participation through the VR space may be a stepping stone for some to decide whether to participate in person in the future.

The AR application, on the other hand, can be used to support in-person social interactions with others in an actual physical space. It allows us to still export the affordances of the virtual worlds into physical space, through a mobile device with the application as a medium, without having to manipulate or rearrange the physical world itself.

Features of B2W

There are five features included in both VR space and an AR mobile application:

- Wayfinding
- User profile box
- Communication
- Moderation
- Sensory stimulation control

1. Wayfinding

Wayfinding comprises techniques people use to orient themselves and navigate in physical space. As previously mentioned, there are many cues that are embedded within the space to facilitate wayfinding in virtual worlds. For instance, there are texts, pictures, and symbols to clearly identify where users are located within the space, and a navigation menu with buttons and hyperlinks users can interact with (i.e., click) to move or jump to another location, much like signages in the physical world. There are also other subtle cues, such as highlighting of clickable buttons when a cursor hovers over it, that inform users how to interact with different elements. Moreover, some virtual spaces have descriptions about the spaces and rules to set clear expectations for appropriate behaviours within the space.

Co-creators shared that visual overlay components in the physical world to highlight certain objects or areas or provide additional information or instructions would be helpful—particularly when they enter a new place. This information helps users to understand the environmental context they have entered.

In both VR space and an AR application, audio and visual descriptions of various elements within a physical space can be overlaid to serve as wayfinding cues to help neurodivergent users orient and explore the new space.

2. User info box

User info box is a pop-up box that appears by each user, via face recognition, in social space. It is inspired by a popular massively multiplayer online role-playing game:

> *In the screen, you can click on somebody and it tells you everything you need to know about them without having to do social interaction and all that stuff. It tells you other social information basically. It's even a magic guy with a lot of strength whatever. It might be kinda cool to have in your virtual space—people could have their own character stats. (John, session 7)*

The purpose of user info box is to aid social interactions by providing as much social information as possible to users to set up for successful social interactions. This includes their name, their role within the space, special-interest tags, icebreaker questions, and off-limit topics. The roles may include facilitator, mentor, participant, and visitor. This information is helpful for people to decide whether they would like to approach the person and how to approach them. One co-creator shared that he is more likely to respond to questions from an administrator or moderator than from other participants he does not know very well. Clearly identifying moderators or mentors may be helpful to indicate who is available to provide support in times of need.

Special-interest tags make users' special interests visible to each other. Many neurodivergent individuals are often passionate about their unique special interests. All three co-creators shared that the challenge in finding others who share their special interests was an added barrier to socially connecting with others. Triggering (i.e., by tapping or clicking) tags also allows users to browse among others who share the same passion in the same space, thereby increasing the possibility of social connections.

Icebreaker questions are provided by users to initiate what might otherwise be awkward first encounters with other users in the space. Viewing the icebreaker questions of other users can also help initiate conversations with them.

> *[At an event I previously attended] there was absolutely no icebreaker at all. So I left without knowing any of those ladies. [...] If I was in charge, I'd do that [icebreaker activity]. everybody could at least say what their name is, so they wouldn't feel like they are excluded. So that'd work for sure for autistic people if they were comfortable to do that. It'd help so much because some of us have such a hard time engaging. (Tammy, session 14)*

On the other hand, off-limit topics are conversation topics that users do not wish to explore with others. This feature is to prevent users from asking questions or making comments about topics that may be offensive to the particular person they are just meeting for the first time.

Much like wayfinding cues, user info box can be added as a visual overlay in the VR space and the AR application.

3. Chatboxes, post-it notes and impression icons

Chatboxes, post-it notes, and impression icons provide three different technology-mediated ways for neurodivergent users to interact with objects and others in the same space. These features are to aid social interactions and not to replace face-to-face conversations in physical space.

Chatboxes are modelled after common instant messaging services, where users can direct their questions, answers, and comments to one or more particular recipients. Messages can be either typed or voice-recorded.

Post-it notes and impression icons provide alternate means for users to interact with objects and each other within the space. Post-it notes allow users to stick their questions or comments anywhere in the space and then wait until it is an appropriate time for them to be acknowledged

and addressed. Impression icons are icons shaped like hearts and question marks that can be placed anywhere in the space. They give alternate and quick ways for users to share their impressions about what they encounter in the space. For instance, if a user sees a painting on a wall that he or she likes, a heart icon can be placed on or near the item. These impression icons can attract the attention of others who share similar opinions and serve as conversation starters.

4. Sensory stimulation control

Sensory stimulation control allows neurodivergent users to control visual and auditory stimuli to which they are sensitive in the VR space or via AR application. Co-creators shared that the presence of certain sensory stimuli such as bright light and loud music makes it challenging for them to process information and communicate effectively with others. Users are able to adjust the colour and brightness of the light in the space. Playing white noise can mask loudness in a crowded space.

Usage of this control can be summarized into a report that may be a helpful communication tool for users to communicate their sensory accommodation needs in physical spaces.

5. Moderation

Moderation buttons allow users to call on volunteer moderators when needed. Volunteer moderators are enforcers of rules and keepers of the safe space, but they are also mentors who can step in and coach through any technical issues or social issues that users may be experiencing with other users. They are either neurodivergent or neurotypical individuals who understand and embrace neurodiversity and challenges neurodivergent individuals may face—daily and across their lifespan. Table 2 summarizes how the affordances of the virtual world are incorporated into each of the five key features (wayfinding; user info box; chatboxes, post-it notes and impression icons; sensory stimulation control; and moderation) of the VR space and the AR applications.

Table 2 The affordances of the virtual world and the five key features of the VR space and AR application

	Safe space to explore and be themselves [S]	**Alternate ways to create and understand meanings [A]**	**Object -centered sociality [O]**	**Moderation [M]**
Wayfinding	[S]	[A]		[M]
User info box	[S]	[A]	[O]	[M]
Chatboxes, post-it notes and impression icons		[A]	[O]	[M]
Sensory stimulation control	[S]			
Moderation				[M]

Setting Up Bridging Two Worlds

The B2W VR space and AR application were designed to be used for making events for a network of neurodivergent individuals in the physical world.

One of the most important elements for a successful social interaction is motivation. Co-creators shared that they need to be motivated in the first place to join events and connect with others, whether this takes place in the virtual or physical worlds. Therefore, it was important for us to identify types of events that may attract neurodivergent people. Co-creators identified making events, where people gather to make things from arts and crafts to digital artifacts, to be an ideal context for them to connect with others:

> *[I enjoy] something that rewards me intellectually. Like going and learning a new skill, figuring out how to do something I've always wanted to figure out how to do. They kind of have something like that called makerspaces, and you know you can go in there and use all the tools they have and find people to make things with. People who have knowledge and that kind of stuff. There are also classes where you go and learn how to do the 3D printer, they've got the laser cutter or whatever. I also enjoy the other things that are in the community where they have maybe an expert that comes and does mini-sessions and teaches people on some topics. (John; session 5)*

> *There has to be purpose! That's the whole creating thing right. If I'm making something I'm engaged. That's what the other guy [John] said, that it has to be intellectually appealing. It can't just be social for the sake of socializing. (Tammy; session 12)*

Through discussions we also identified, particularly for neurodivergent individuals, three broad benefits of making:

1. The act of making is intentional and purposeful. There are always tangible-end products.
2. Making promotes object-centered sociality. It brings people together in a common time and space for both digital and physical making projects.
3. The process of learning skills to make something and perfecting the product is also social in nature. Whether you are reading manuals written by someone or asking someone a question, you are relying on knowledge and experience of another person. Also, because you are motivated to make your project, you are likely more motivated to reach out to others. Indeed, there are many emergent communities developed out of shared interests of making projects.

Prior to making events, event organizers would be responsible for setting up the wayfinding features for both the VR space and AR application ahead of time for the predetermined event location. The registration process, however, allows registrants to enter their own information that can be loaded into user info box by the event organizers. Registrants also have to provide their photos for facial recognition purposes—so that their corresponding user info box can be shown when other users gaze at their faces in the VR space or through the AR application. The backend

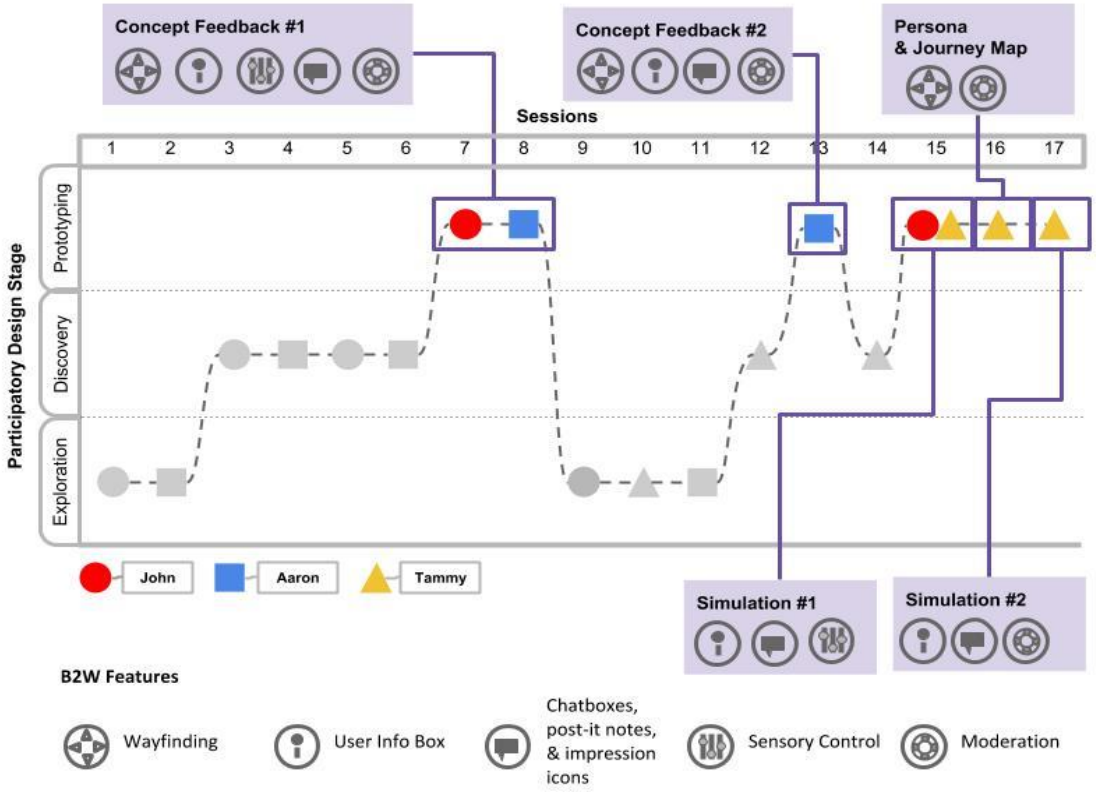
process of setting up both the VR space and the AR application must be refined in the future, so that they can be easily used across multiple events.

The sensory modulation feature is not dependent on the event space and does not need any adjustments prior to the event. As well, volunteer moderators must be recruited ahead of time. In addition to providing moderators with information about the event; their roles as moderators; and features of the B2W VR space and AR application, providing volunteers with resources about common issues and tips on how best to support users through these issues would also helpful.

Prototyping Process

The VR space and the AR application ideas and their features (wayfinding; user info box; chatboxes, post-it notes and impression icons; sensory stimulation control; and moderation) emerged and were refined through a series of co-creation activities as outlined in the Methodology section of this paper. In this section, I summarize, with selected highlights, the prototyping process which led to the final prototypes that are discussed in the next section. Figure 2 shows features that emerged from each prototyping activity.

Figure 2 Iterations of features of VR space and AR application across co-creation sessions.



1. Concept Feedback #1

The first concept feedback was the beginning of exploring how we might be able to export the affordances of the virtual world into physical spaces. Our design ideas and all five features incorporating the affordances began to emerge here. For this activity, there were two design concepts that the co-creators evaluated: a virtual community for teenagers and AR application ideas for autism.

For evaluating the design concept for the virtual community, the co-creators were provided with three wireframes of the virtual community my colleagues and I had drafted a year prior to the study. The wireframes showed sketches of what the platform might look like from one user's perspective and how users might interact with each other as they move through the virtual space. Navigation aids such as a menu and a map which clearly identified where users are in the space

attracted co-creators' attention and became seeds for the wayfinding feature. Reviewing the wireframes also led us to discuss ways to make social information and rules visibly available to facilitate positive social interactions. The idea for user info box was born during this discussion. The importance of availability of technology-mediated social interaction via text and voice chats and moderators in promoting positive interactions in the space was highlighted as well.

For evaluating AR application ideas for autism, they were provided a post on Medium, ARKit and Autism: New Futures (Smith, 2017), which summarized ten AR application ideas. They were asked to then choose three ideas that they found valuable and could be incorporated into our prototype. These AR ideas, especially those that focused on adding annotations to people and objects, and changing brightness and colors in the physical environment, inspired us to later explore how AR technology can mediate our experience and social interactions in the physical world.

Therefore, all five features of the VR space and AR application—wayfinding; user info box; chatboxes, post-it notes and impression icons; sensory stimulation control; and moderation— were inspired by the affordances we found in the existing design concepts.

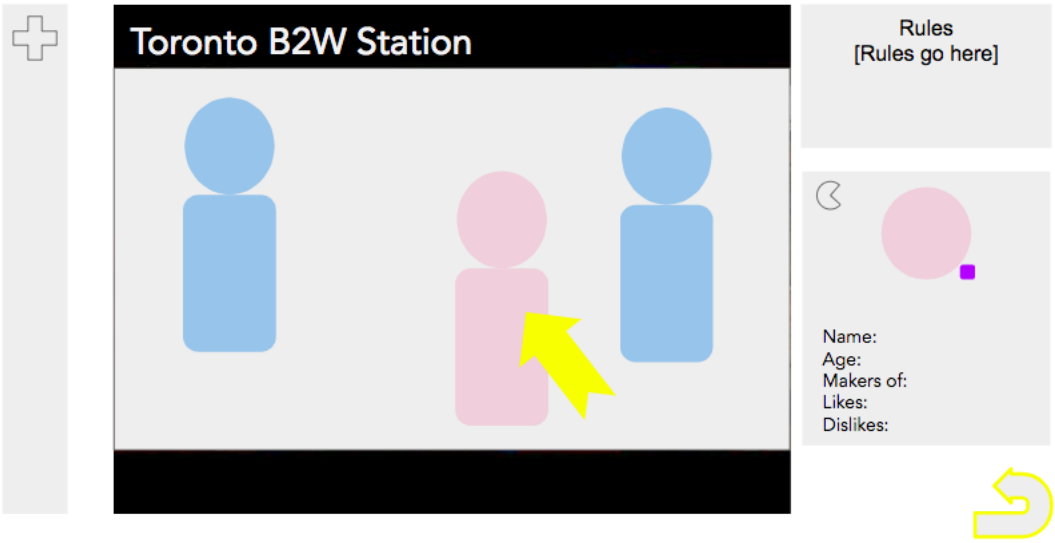
2. Concept Feedback #2

The purpose of the second concept feedback is to further explore our emerging ideas. For this activity, Aaron evaluated a low-fidelity prototype of a virtual platform I put together based on the ideas generated from the first concept feedback activity.

The prototype demonstrated how users could remotely access a live making-event taking place in the physical world through a virtual platform. The platform resembled an existing video

conferencing platform such as Adobe Connect[8] and Zoom[9] in its appearance. As shown in Figure 3, users can stream and view the video of a live event on the platform. Clicking on people on the video view would load user info box which would appear on the right side. A chat button embedded in user info box would allow users to send messages to that particular user if they had any questions or if they found the provided information intriguing. The rules for the event are posted on the top-right corner at all times.

Figure 3 A low-fidelity prototype of virtual platform.



To improve on this prototype, Aaron suggested adding more visual descriptions of objects and people in the video. He particularly focused on clearly identifying roles of different users (e.g., moderators and participants) in the user info box to help him navigate and interact with others.

Although we mainly focused on telepresence rather than presence in a physical space during this activity, the idea of adding visual information was instrumental in developing many of the features such as wayfinding, user-info box, chatboxes and impression icons.

[8] https://www.adobe.com/products/adobeconnect.html
[9] https://www.zoom.us

3. Simulation #1

Building on the idea of remotely joining in a live event through a virtual platform, both John and Tammy joined for a simulation activity. John and Tammy played the role of remote participants for a 3D printing event, and I the role of a moderator and a facilitator. The simulation consisted of two components: (1) a web-based 3D viewer, SphereShare[10]; and (2) a live web conferencing platform, Google Hangouts. Combined, these tools mimicked how users would view the event space using a VR viewer. Since John and Tammy were not able to control the view angle in SphereShare, I used a handheld video camera to simulate more flexible viewing and navigation of the space, which they could see in the video view of Google Hangout.

For Tammy, who has never been to a makerspace, this session was more real than the simulation that it actually was. The VR space created an opportunity for her to experience an event she never would have even known about otherwise. It also created an opportunity to meet someone new, John. While both had consented earlier to participating in the session together, they shared that they experienced introducing themselves to each other as being inevitably "awkward." This experience could have been mediated (and thereby less awkward) had there been more information about John and an icebreaker activity. This prompted us to further refine our user info box (i.e., by adding icebreakers).

Interestingly, both John and Tammy shared that they would still would have preferred to have been in the makerspace in person. This may have been a result of challenges experienced during the session such as technical issues and a sense of disembodiment. Or, it may suggest there is no true replacement for experiencing the physical world in person. This finding led us to further explore the AR application idea to support social interaction and participation in the physical world.

[10] http://sphereshare.net

Unfortunately, technical difficulties resulted from poor internet connectivity and unfamiliarity with the conferencing tool that was used for the session. These resulted both in significant delay in getting the session started and continued interruptions throughout the session. While frustrating, these challenges reflected real-life implications for the use of the VR space and other technology-mediated interactions.

4. Persona & Journey Map

Following the first simulation, Tammy was asked to create a persona who was a young neurodivergent individual who would be using our design idea.

> My name is Mandy.
>
> I am 15 and I love cats. I am not very good at sports but I like to go hiking and fishing. I like to read Stephen King books and sometimes watch scary movies. I like pizza. I like seeing movies in the theatre. I love listening to music. I have two cats and three hamsters. I am in grade 10 and don't like school very much. I play the flute in the school band.
>
> I am very shy. I don't really have many friends at school and don't feel like I fit in. People don't seem interested in the things I am. I get very bored at school and spend a lot of time alone at home. I would like to know some people like me. I wish I had someone to do crafts with. I have a hard time meeting new people. I like to learn new things but it is hard to be around people and feel comfortable. If I can participate online I might be able to share more and connect better than I do in real life.
>
> I have very low self-esteem. My parents don't think like I do and everyone just tells me to be a certain way I'm not. I get very frustrated and want to just be accepted for who I am and not be told I'm bad.

Tammy was asked to use her persona, Mandy, and to imagine her participating in a live making-event via VR space and in person. This activity was to identify specific aspects of the VR space and experience that might then lead up to its use in physical/in-person space and that could be further iterated. The journey map visualizes Mandy's experience from discovering about a maker workshop, to the first workshop in the VR space to the first workshop in the physical world.

The journey map activity revealed areas of improvement for the VR space. These included the following: camera angles; descriptions of various equipment in the room; and patience in explaining/responding to Mandy's questions. The first two areas highlighted that the use of a VR headset to access the VR space with the wayfinding feature is indeed important to make users' experiences more immersive and exploration of the space more intuitive. The third area, patience in explaining, suggests a role for moderators who could support Mandy to participate and interact with others in the space. Therefore, wayfinding and moderation features were elaborated further in the final prototypes.

5. Simulation #2

For the final simulation activity, Tammy assumed Mandy's persona again to explore the VR space and AR application. This time, instead of simulating the workshop with video, Tammy was provided with two still-photographed scenes of a making workshop with virtual post-it notes she could use on the side of the pictures on Google Slide. Tammy was able to type her comments and the questions that she had on these post-it notes and place them near relevant spots on the scene. Without any wayfinding features embedded in the photos, Tammy wrote on post-it notes a lot of questions about different objects and people in the scene. Post-it notes also allowed her to write her comments and questions about her surroundings that did not need immediate attention. For instance, she typed "Is that a picture of a bridge? Where is it?" and placed it near a painting on the wall. This activity inspired the post-it notes and impression-icons features in addition to the chatboxes. A need for a way in which users can communicate with moderators in both VR and physical spaces was also demonstrated during this activity. Tammy anticipated that Mandy would experience anxiety attending an event with novel people, and she felt that moderators would be essential to support her.

Here, we again found that having alternate means to ask questions and communicate by using text or other social objects as well as having mentors would be beneficial to be successful in a physical space.

This simulation session concluded co-creation activities with the co-creators. Following the final session, I continued to work on refining the prototypes of the VR space and AR application with the five features (wayfinding; user profile box; chatboxes, post-it notes and impression icons; moderation; and sensory stimulation control) identified during our time together. The resulting final prototypes are discussed next.

Final Prototypes

The final prototypes demonstrate the ways users would interact and experience the key features of the VR space and AR application. Both prototypes were created for mobile devices in Unity® Software[11], a game development platform.

B2W VR Space Prototype

The VR space can be accessed by using a compatible mobile device and a VR headset (Figure 4). Upon putting on the VR headset, a user is able to virtually "enter" the event space that is taking place in the physical world. The current prototype demonstrates three features of the VR space: wayfinding, user info box, and sensory stimulation control. In the current prototype, users interact with objects in the space via eye gaze. In the figures below (Figure 5 to 8), white circles represent a point at which a user is gazing. A user info box (Figure 5), for instance, would appear when a user gazes at the face of another user in the VR space (Figure 6). Similarly, with eye gaze as well, users can trigger wayfinding information by gazing at pre-set hotspots. For instance, gazing at a making

[11] https://unity3d.com/

tool such as a laser cutter that would be used during an event will trigger its description to appear above it (Figure 7). They can also trigger other buttons such as a light switch button (Figure 8) for sensory stimulation control. The buttons are always available to the users' view in the VR space.

Figure 4 A mobile device, ZenAR Fone, and a VR headset.

Figure 5 Example of user info box.

Figure 6 Example of user info box being triggered upon gazing on a person in the VR space.

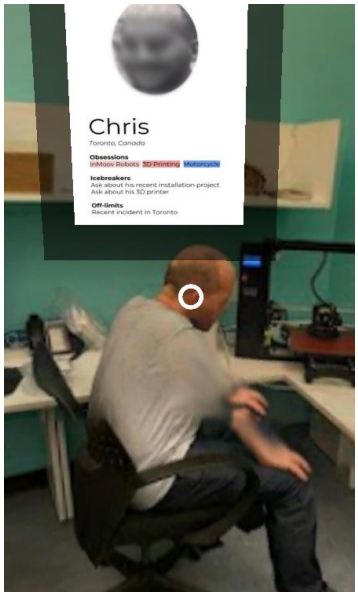


Figure 7 An example of wayfinding feature with the description of a laser cutter in the VR space.

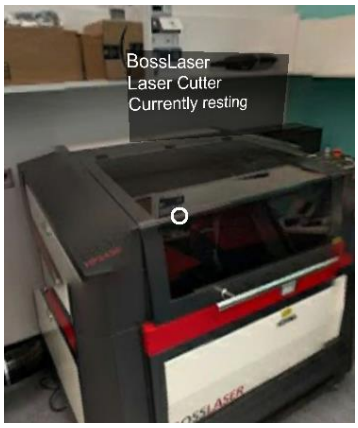
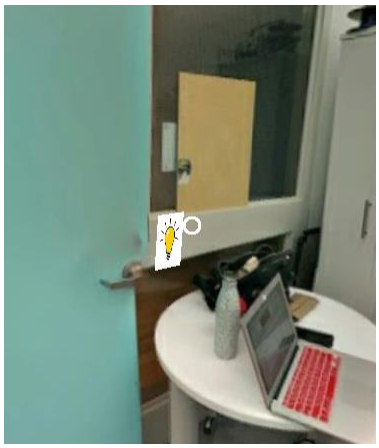


Figure 8 Light switch for sensory stimulation control.



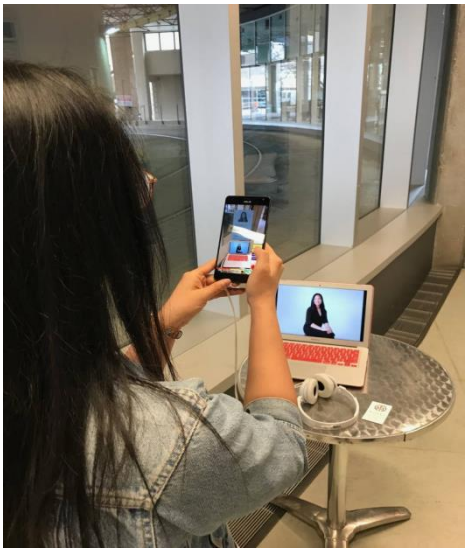
B2W AR Application Prototype

The AR applications can be used on a mobile device with a camera that supports AR functionalities. Users interact with the features of the AR applications on the screen of their mobile device. The current prototype demonstrates three of the key features: user info box, impression icons, and sensory stimulation as shown in Figure 9 and 10.

Users are able to view user info boxes of other users in the space by pointing their mobile device's camera towards a person. Once the application recognizes the face, the user info box appears above the person. To leave an impression icon, users point their camera towards a spot where they want to place the icon and press on the impression button. Impression icons are persistent (i.e., when a user moves the camera away from the icon it disappears from the screen, but when the user points the camera towards the same spot again, later on, the icon reappears on the screen) and visible on the screen of the mobile devices of others as well. Impression buttons and sensory stimulation control buttons are always available on the screen, so users can interact with them anytime.

Figure 9 Layout of AR application on the screen of a mobile device.

Figure 10 Testing the user info box feature on AR application.



Final Thoughts

The co-creators and I embarked on this study with two goals in mind: (1) gain a better understanding of the unique affordances of the virtual world that allow neurodivergent people to express their thoughts and connect meaningfully with others; and (2) co-design with neurodivergent adults social spaces in the physical world that incorporate these affordances. Through a series of iterative and inductive co-creation activities we were able to identify four core features of the virtual world that support the co-creators particularly in participating and connecting with others in meaningful ways in the virtual world: safe space to explore and be themselves; alternate ways to create and understand meanings; object-centered sociality; and moderation. Our finding verified some of the findings of the existing literature on the benefits of virtual worlds for neurodivergent users.

Throughout the study, co-creators shared that they see and hear, feel, and understand the world differently than many of the neurotypical other people they meet in the physical world. As a result, they are often misunderstood. They also preferred to interact with others through objects and

activities rather than having casual conversations. As they mature into adults, some felt that they needed to be and act as though they were someone else, trying to see and act like everyone else around them. However, the gap between how they experience and understand the world and how the physical world is organized remains. This gap sometimes makes it difficult for them to connect with others in the physical world.

The VR space and the AR application we designed incorporate the affordances of the virtual world so that users can navigate and interact with others in the physical world in similar ways as they do in the virtual world. Audio and visual descriptions of the different spaces and objects in the view help users to navigate the space either via the VR space or in person. In the VR space, users are able to explore while remaining invisible to the rest of the people in the physical space. The user-info box gives users access to all the important social information about the other people in the space without having to engage in small talk, and it helps users find those who share their special interests. The user info box also provides guidance on how to initiate conversations with others by providing suggested icebreaker questions and off-limit topics. Chatboxes, post-it notes, and impression icons allow users to interact with others through social objects, in addition to the verbal communications we often rely on during in-person interactions. With sensory stimulation control, users can adjust visual and auditory stimuli to their preference. Finally, a moderation feature that connects users and volunteer moderators ensures that in times of difficulties in the physical space users can access the help of someone who understands how they experience and understand the world.

The iterative and hands-on nature of the co-creation process actively engaged co-creators and resulted in unexpected and rich insights into their experience in both the virtual and physical worlds, as well as their perceptual and cognitive processes and preferences. For instance, testing

out a concept generated feedback about what they liked or disliked, and their ideas for improvement revealed their communication and interaction preferences supporting the neurodiversity perspective.

However, our time together was not without challenges. Relying completely on online tools to create, evaluate, and edit prototype ideas limited activities due to the technical issues with internet connectivity, as well as the varying comfort levels of co-creators with technology. At times, a sense of disembodiment also posed another challenge. Additionally, while it was an intentional decision to recruit adults to leverage on their own experience as teenagers, we are conscious of the fact that our findings may not generalize to teens of the current times. For those with limited technical and design backgrounds, the act of "imagining" components of a technology that does not exist was, at times, challenging as well.

Nevertheless, we were able to successfully come up with VR space and AR application ideas through our time together. Our design ideas provide alternate means for neurodivergent individuals to participate in activities and interact with others in the physical world. With the VR space and AR application, neurodivergent persons no longer have to put extensive efforts into changing themselves to fit into the physical world—a world that often does not meet their perceptual and cognitive styles. The VR space, especially, may create a bridge between the virtual and physical worlds where neurodivergent individuals, who are often isolated, can connect with each other and with neurotypical individuals and have meaningful and positive interactions. Although both of our design ideas were not intended for a therapeutic purpose, the successful social experiences that result from their use may lead to a therapeutic effect for the users, since it has been shown that involvement in social and recreational activities increase one's quality of life (Bishop-Fitzpatrick, Smith DaWalt, Greenberg, & Mailick, 2017). Further, the VR space can also

benefit anyone who wants to participate in activities in the physical world but are not able due to various reasons such as geographical barriers and barriers created by the physical environment.

Future research should focus on testing and evaluating both of our design ideas with neurodivergent individuals. Also, more work needs to be done on identifying and appreciating neurodiversity—how each individual experiences and understands the world differently from each other. Other areas that should also be the focus of further research include creating embodiment of remote participants in the virtual space (Steuer, 1992) and creating methods and tools with which neurodivergent persons can participate in activities through interacting with objects and other people in the physical world.

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Appendix A: Semi-structured Interview Guide

1. Share something unique about yourself.
2. What does "being neurodivergent" mean for you?
3. Describe your community (i.e., Wrong Planet, Autcraft or a blog).
    a. What makes this (i.e., Wrong Planet or Autcraft) a community?
4. What made you create/join this community?
5. Did you join the community in adolescence?
    a. If yes, how did taking part in the community help shape who you are today.
    b. If no, do you wish that you had found the community in your adolescence? Why or why not?
6. What technical tools (hardware and software) do you need to participate in the community?
7. How do you navigate around the virtual community (e.g., to go from one place to another, to find information, to wander, etc.)?
    a. What are some features of the virtual world that allow you to do this?
    b. How is this different from (or same as) navigating in the physical world?
    c. We often use some or more of our five senses (i.e., sound, vision, touch, smell and taste) to navigate and make sense of our world. What senses do you use to navigate the virtual world?
8. How do you interact with other members and participate in the community? How do you belong?
    a. What are some features of the virtual world that allow you to do this?
    b. Can you have same types of interactions and participations in the physical world?
9. How often do you visit the community and approximately how long do you stay on each time?
    a. When you "log off", do you feel connected or disconnected from the community?
10. How would you improve on the community if you had all the power and resources?
        a. What features would you add or remove for adolescent users?