Exploring Collaboration in a Blended Reality System: A User-Perspective Study

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***Abstract*—The development of eXtended Reality (XR) technologies has led to an increase in the use of virtual spaces to help support collaboration. However, collaboration between physical and virtual environments is often considered solely with respect to how successfully the XR technology has been used to integrate virtual and physical worlds. In contrast, this study explored how participants collaborated within a Blended Reality (BR) system, with the overall aim of identifying the benefits and challenges associated with BR systems during group collaboration. Analysis of interview and video observations highlighted various beneficial affordances and considerations associated with different elements of the BR system. There were benefits associated with the physical, virtual and blended space as well as considerations relating to the task design and system design. Further work should seek to determine how to design BR spaces to better suit the collaborative context.**

Keywords—collaboration, physical space, virtual space, Blended Reality, user focus

I. Introduction

Collaboration is a ubiquitous component of modern society and has been defined as: "the involvement of people interacting with one another to work towards and achieve common goals" [1][2]. Following the Covid-19 pandemic and recognition of a more globalised workforce, there is a clear desire and need to support collaboration relative to remote and co-located ways of working [3]. This has resulted in a notable increase in the research and application of eXtended Reality (XR) technologies that encompass a combination of virtual and augmented experiences, with the aim of enabling and supporting remote collaboration. Blended Reality (BR) is one such example. BR can be defined as "an interactive mixed-reality environment where the physical and the virtual are intimately combined in the service of interaction goals and communication environment" [4]. This is achieved by creating blended spaces, "where a physical space is deliberately integrated in a close-knit way with a digital space" [5]. Bower et al [6] outlined some of the specific characteristics and ways in which these spaces could be integrated, highlighting, at the minimum, the need for users to hear and see each other within and between each space.

A. Aims and Approach

Much of the BR-associated research to date has taken a technology deterministic approach, with studies aiming to evaluate new and increasingly complex technological implementations and integration of XR [8][9], leaving fundamental user-centred questions unanswered. Whilst these studies also comment on the behaviour of users, they fall short of exploring/defining specific user requirements to enable effective collaboration. Consequently, 'collaboration' within these environments is often considered solely with respect to how successfully the XR technology has been used to integrate virtual and physical spaces [10] [11]. In contrast, a human-centric approach can elucidate which elements of the BR system are most effective from a user's perspective, as well as uncovering the reasons behind their behaviours and preferences.

This study aims to address this gap by taking a human-centred approach to the evaluation of BR case study-in order to highlight the benefits and challenges to collaboration when users interact in BR systems.

II. Design and Method

The study was conducted over a series of University seminars as a case study for data collection and analysis. In this case, the BR system was designed to be easily accessible for participants, allowing for choices to be made about how to interact whilst adhering to educational requirements and learning outcomes. The naturalistic design of this study was critical as it preserved user agency (i.e. the freedom for users to behave as they desired). Participants were given the choice of which space to inhabit for each lecture/seminar, how they completed tasks, and if/how they worked with other group members. Due to the educational context, there were some elements that were controlled to meet the requisite learning outcomes. For example, participants were instructed to form groups for their seminar sessions and were encouraged to maintain the same groups in each of the sessions. They also had specific set task/s to be completed, although it is noted that this naturally provided an opportunity for collaboration to occur.

A. Participant Groups

Participants were a mix of postgraduate students enrolled on a Human Factors methods module at the University of Nottingham, UK, with an average of 40 students attending each week. All students were aware that they would be working together within a BR system during the seminar to meet learning outcomes and consolidate their knowledge. Students worked in self-selected groups, from which three 'case study' groups, comprising of 5, 5 and 7 students, were chosen for this analysis. Each group was required to select a

TABLE I. THE THREE SEMINAR SESSION TASKS SET

Session	Task description
Task 1 - Psychophysics	"Design a psychophysics experiment to investigate how accurately people can judge the relative size of a 'human' object" (Lego figurine): Physical space task – "Set-up the physical experiment with group members acting as participants to judge distances between objects (Lego)." Virtual space –"Virtual users collect 'tips' located around the virtual space and bring them back to the shared whiteboard in the group's 'private' room. These tips will help physical members to set-up the experiment."
Task 2 - Video Analysis	"Watch the video within the virtual space and develop codes that relate to the behaviours. Code the videos individually and then come together as a group to discuss the codes."
Task 3 - Methods	"As a group, decide on a brief provided and make notes based on the questions on the shared whiteboard relating to the methods that may be used for the chosen brief."

'node user' to act as a bridge between the virtual and physical spaces. This user was explained to the students and was required to be present in both the virtual and physical space with the intention of supporting collaboration between the spaces via their communication channels. Node users were either self-selecting or nominated by their group.

B. Tasks

The data collection period occurred over three seminar sessions in the consecutive weeks following an initial piloting exercise. The cohesion and collaboration of the groups were assessed to ensure that they was observable. During each seminar, participants were required to undertake a different task, with specific task elements and instructions relevant to each of the virtual and physical environments (Table I). Participants were informed of the task relative to their own space (virtual or physical) for each session and were reminded of their fellow students in the other space. Each task provided a range of different task elements and demands. The first task (Task 1) provided a context in which there was a designated task for each space (virtual and physical) that led to a shared outcome (in this example, designing an experiment). Task 2 focused on the virtual space with participants being required to move around the space to access relevant information. Task 3 was primarily a discussion task in the virtual space. The participants in the physical space partook in task 2 and 3 via the node user who interacted with users in the virtual space on their behalf, allowing physical space users to contribute to the discussion.

C. Spaces

The physical space was a large lecture theatre in which participants could decide where they sat and worked, with the only stipulation that group members should be seated together. The virtual space was created in a free-to-use, browser-based software, 'Gather Town' (https://www.gather.town/), which could be accessed via different devices (mobile phone, laptop etc.). Gather Town is an online, proximity-based 2D platform with a visual 8-bit design that allows users to access and move freely within a 'space' using avatars [12]. Users could communicate with other users through video and audio channels (both of which were proximity-based as a form of spatial communication), and through chat and avatar/emoting channels. In addition, Gather Town provides users with interactive objects, such as a virtual whiteboard, go-karts, pet animals, etc.

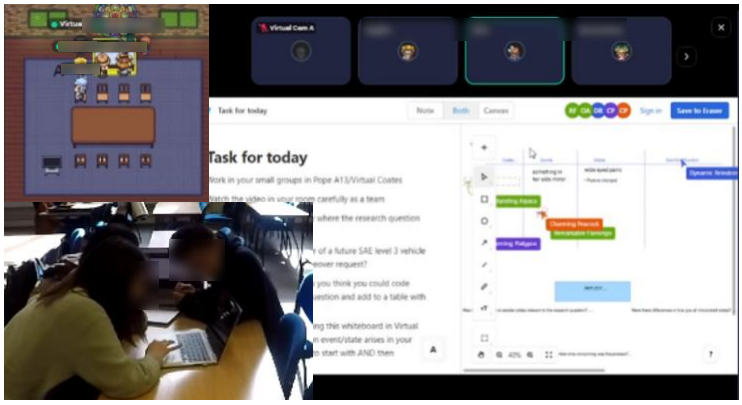

Fig. 1: Screenshots of a group working on the video analysis task. Virtual space top left, physical space bottom left, virtual whiteboard with information on the right.

The virtual whiteboard was important for all tasks during this study as this was where participants could access and record information relevant to the task. It allowed remote and physical participants to have access to the information at the same time. A whiteboard was also chosen as a recognised collaborative tool that would be familiar to participants [13]. An example of the collaborative environment (task 2) can be seen in Fig 1.

D. Methods and Design

An exploratory research approach was adopted to elicit understanding from the users' perspectives. Data were captured using semi-structured group interviews and video observations.

Group interviews were conducted after all three sessions had taken place, with the aim of gaining insights into what the groups thought about collaborating within the BR system. All interviews were transcribed, ensuring anonymity. Transcripts were subsequently analyzed using a hybrid approach to thematic analysis [15], whereby themes were formed inductively based on interview responses and then compared against collaboration literature in a deductive manner. To structure this, the CoSpaces Collaborative Working Model [2] was used as a holistic representation of collaboration factors derived from Human Factors research.
Video data were captured for each session and analyzed with the aim of highlighting novel interactions or scenarios, including communication between participants and the BR system, and to support the findings from the thematic analysis. Social Network Analysis (SNA) was conducted on communication data to generate a visual representation of the collaboration based on how information flowed between agents relative to the context [16][17]. The social networks are formed via nodes (agents involved) and the edges between them with arrows to highlight who is communicating and the direction of the communication (or interaction with non-human agents). Results of the thematic analysis are presented below with SNA and video excerpts used to complement findings.

III. Results and Discussion

Five themes were highlighted which relate to the *space*, the *system* and the *task* (Table II).

A. Theme 1 – Affordances

The characteristics of each space (physical, virtual, blended) naturally afforded different activities and behaviours (Table III). These affordances highlight the features of the spaces that users recognise as familiar and/or beneficial. Participants used their knowledge and experience of these features to help determine which space to join for each session. Interviews showed that virtual users felt that the virtual space afforded fun and enjoyment: "*the beauty of virtual worlds is that you can do something that you can't do in the real world. I think that helped with engaging each other and make the course more fun.*" (P2). This was created through the 'playful' nature of the Gather Town platform, the ability to adopt an avatar ("*it was fun, you have avatars and you can dress them up*" – P6), and interactions with virtual objects in the space ("*driving the kart, I think it was really nice*" – P5). Participants also reported that the virtual environment afforded more convenience than the physical space, allowing them to join seminar sessions from any location: "*it's a convenient way to join the class because it's early morning, or there's been a storm, or you're not feeling good*" (P1). Physical users reported that the physical space afforded 'familiarity', as the majority of their University teaching also took place on campus. Familiarity was also reported as a beneficial affordance in relation to interaction with the lecturer: "*there was more interaction with the professor*" (P6), and other students: "*if I go in person, the interaction* […*with my teammates*…] *would promote the acquaintance*" (P4). This highlights that the ability to build a personal relationship is considered important for users. Familiarity also extended to ways/behaviours of working: "*If someone seems engaged you would join the work and come into the group, that's when conversations would happen*" (P6). The nuances of other group member behaviour was recognisable in the physical space allowing users to "*see cues*" (P6) and then interact based on the responses, resulting in a natural progression of the collaboration.

TABLE II. Themes Highlighted

Element	Theme
Space	1. Affordances
System	2. Types of communication 3. Purpose of virtual space features 4. Blended space method
Task	5. Information placement

TABLE III. Benefits with Associated Affordances of the Spaces

Space	Affordances	Benefit
Virtual	Adaptability/leverage	Fun/Enjoyment
		Convenience
Physical	Familiarity	Better for interaction with lecturer and some activities
		Understanding behaviours, ways of working
Blended	Connection	Flexible way to provide connections to others
	Increased engagement	Higher level of interaction (compared to videoconferencing)
	Ease of use	Capable of learning the system (overcoming learning curve)

In relation to the blended aspects of the collaboration, students reported having access to both physical and virtual spaces afforded flexibility in their connection with others: "*it provided the flexibility if you were geographically in a different place, it still made you feel connected to other people*" (P8). Reports also indicated an increased engagement with tasks and the module as a whole especially compared to videoconferencing alternatives: "*This is definitely better than attending a virtual meeting or Teams, this is steps higher than that*" (P3). Finally, users highlighted the ability to overcome learning curves associated with the system contributing to the ease of use: "*towards the end* […*of the module*…] *it started getting better. I think the last session we had on Gather was pretty smooth*" (P3). Overall, the benefits that users found within the BR system highlight the affordances that can be useful for their collaboration.

B. Theme 2 – Types of Communication

Both the virtual and physical space enabled visual and audio communication. Visual communication consisted of video feeds from webcams and text through the chat functionality, whilst audio mainly captured speech.

The chat functionality as a feature offered a novel component to the collaboration. On one hand, some virtual users used the chat to communicate. However, other members regularly failed to check or forgot about the chat for periods of a time ("*I don't always see that chat*" – P1). This was especially prevalent during busy periods of discussion and could have resulted in certain virtual users being left out of the discussion. This also seemed to impact how the group worked together and the participants perception of how to respond: "*but then if people are typing, we need to read it, it takes time*" (P5); "*if someone's typing it's a bit weird to tell them on voice 'okay' it's weird, right?*" (P5). This indicates that the space (physical or virtual) can have an impact on communication preferences, and by simply providing different communication options this may be insufficient to ensure the usage of these channels. Communication options which may work well in a completely virtual scenario (e.g. text chat), may not work so well across BR spaces: this should be accounted for in the design of BR.

Reasons for the lack of use of the chat function in BR may include the perceived inefficiency of this method of communication, especially compared to speech and video. Participants also may have been unfamiliar with this way of communicating, resulting in an increase in the time taken to recognise that the chat information existed, as well as how to respond to this information. This highlights a need to consider the intention behind the inclusion of different communication channels and modalities within a BR system and how to ensure that these are effective and beneficial.

This also applies to the intention behind behaviours: "*I used to leave my mic on … so that people … know I'm available to talk or interact"* (P4). This could have been used to overcome communication issues such as not being able to pick up on nuances like "*emotions*" [P1] and "*facial features*" [P1] available in the physical space. However, such behaviours may not have been interpreted by others in the same manner, highlighting a potential mismatch between the intention of a behaviour and the interpretation between users. Therefore, the methods and modalities for communication need to be considered in relation to behaviours which are unique to BR,

rather than simply 'borrowed' from either physical or VR-only communication norms.

C. *Theme 3 – Purpose of the Virtual Space Features*

Users in the virtual space are not necessarily restricted by the social norms associated with the physical world and can subsequently engage in unique, unexpected or even 'fantastical' experiences. For example, participants in Gather Town could engage in virtual dancing, and this can have an impact on social cohesion. In one of the seminar sessions, virtual dancing was proposed and shared between other virtual members and the node user. This resulted in the splitting of the physical and virtual spaces as physical members could no longer be involved, whilst virtual users seemingly became closer by sharing in the dancing activity: "*Another thing is that when everyone has the freedom to go around anywhere, dance around, it's very hard for me in a physical world*" (P1). The difference in social cohesion created by the virtual dancing is shown through visualization of the social network, in Fig 2. In the figure, the prior collaboration and task working was shown by all members interacting with the shared whiteboard (blue diamond). Physical members (orange circles) were communicating with each other whilst virtual members (red circles) were also communicating with each other. This was shown by the edges between the orange nodes and the edges between the red nodes. This information was also being transferred between the spaces via the node user (green circle) who was also part of the discussion. This highlights a successful collaboration between the spaces and suggests that members were working effectively on the task. However, when the social activity (i.e. dancing) was proposed by virtual members, these communication ties were broken between the node user and the physical members, resulting in the separation and independence for members in each space. This finding highlights the need to better understand features available in the virtual space and how these might impact on the BR group as a whole, especially if they support one space at the detriment of the other.

The features of the virtual space also refers to the association to (and potential misrepresentation of) the physical space: "*So that kind of feels more unreal, like the dog and all those things* [plants, go-karts etc.], *we don't have it. For me it doesn't give the sense that I'm sitting in a classroom*" (P1). Although it is not clear whether the association, or lack of it, is beneficial or not, it does indicate that users recognise a mismatch between spaces; this could inform their perspectives of the spaces. It also shows the importance of understanding how the virtual space can be leveraged and what the purpose of the features are, specifically in relation to the physical space and the task at hand.

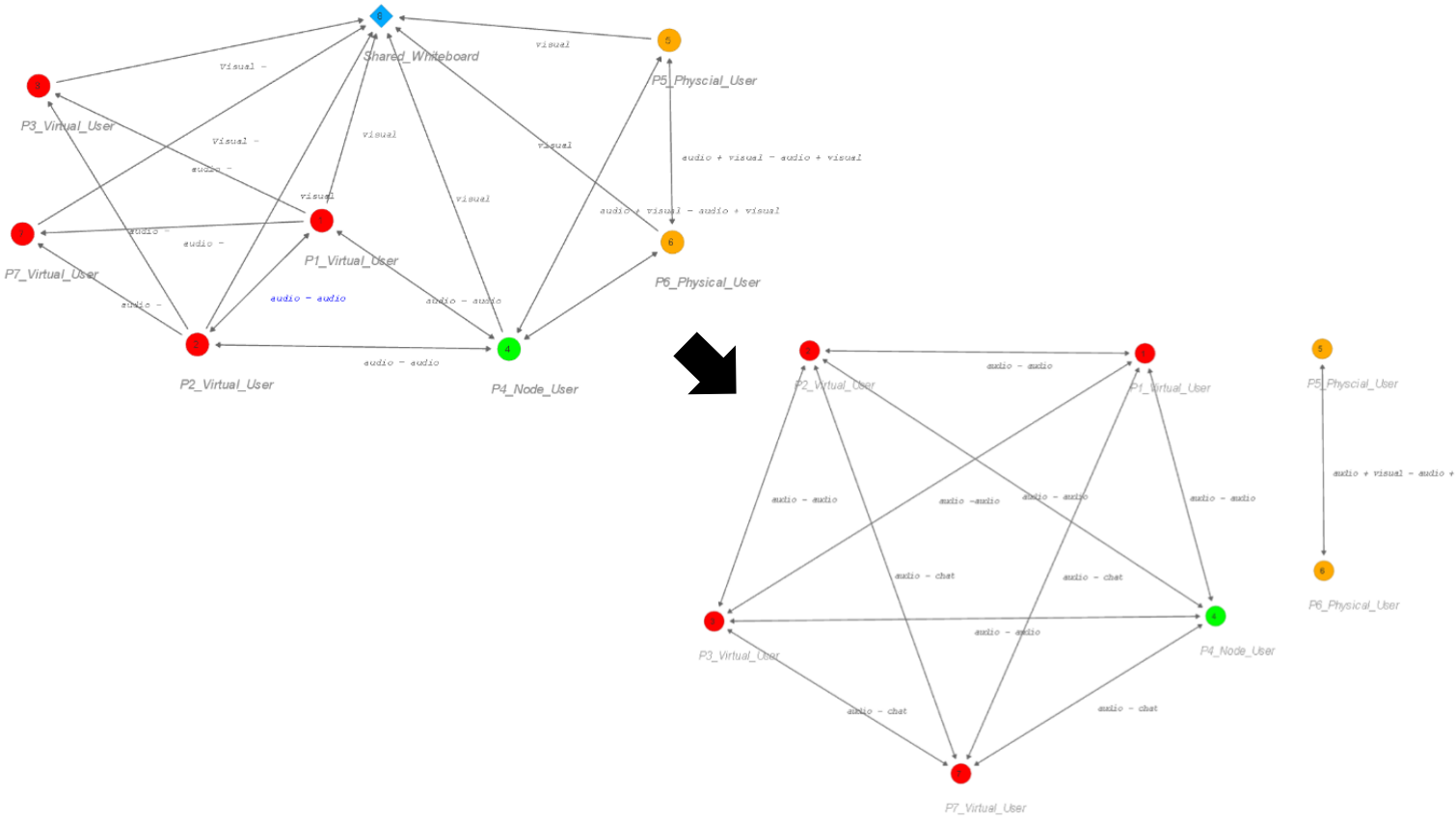

Fig. 2: The group transition from working together on the task earlier in the seminar session to splitting into two separate spaces towards the end (in response to virtual users dancing). Red circle = virtual user, Orange circle = physical user, Green circle = node user, Blue diamond = shared whiteboard.

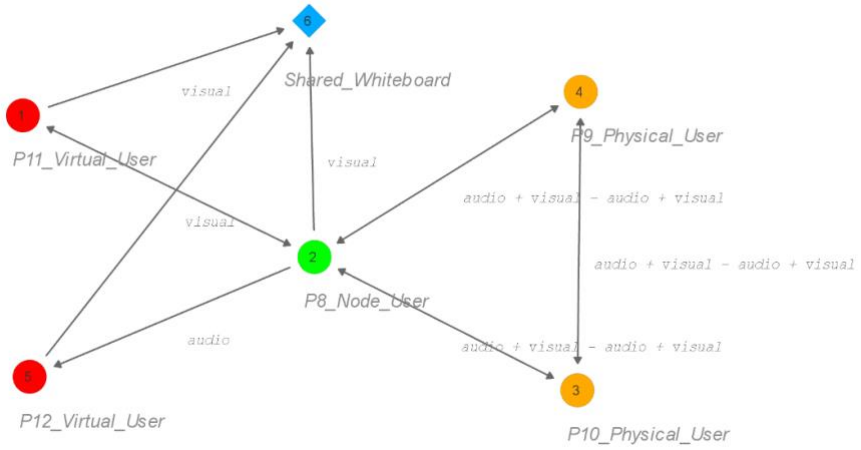

Fig. 3: Example of the node user (green) being the connection point within the BR system. Red = virtual user, Orange = physical user, Green = node user.

D. Theme 4 – Blended Space Method

A node user was selected from within each group to act as a bridge between the virtual and physical spaces. Node users highlighted the challenges associated with this role, for example, an increase on workload and awareness associated with providing the link between spaces: "*I felt that like my avatar had to represent everybody else who was in the group… I did find it a bit challenging*" (P8). Other group members highlighted logistical issues, such as having to use only one device to fulfil the node user role and to also contribute to the task. "*I was like trying to use P8, to look at the whiteboard on* P8*'s laptop. And sometimes that was quite challenging. Also, I couldn't really contribute my own ideas up at the same time*" (P10). Further challenges occurred in situations in which other physical members circumnavigated the node user by joining the virtual space themselves to access the information on their own devices. This raises the question of whether a node user as a joining method is necessary in a BR space. Furthermore, this evidence seems to suggest a possible trade-off between convenience and collaboration. The node user offers a method of facilitating collaboration for both spaces, yet simultaneously acting as an additional barrier by being the *only* point in which collaboration can occur. This problem is illustrated in the social network in Fig 3. This shows that the node user was a central point between virtual and physical users through which communication travelled as all edges pass through P8 and out to the other nodes (including P8's communications). However, this also suggests that the node user could act as a bottle neck, as seen by the absence of edges between P9/P10 and P1/P5. This could have resulted in a delay in information transfer that could have otherwise been achieved more efficiently through direct communications.

E. Theme 5 – Information Placement

A final emergent theme was the placement of task-related information (i.e. information that was required for successful task completion). For example, in situations where the task predominantly occurred in the physical space, it could be difficult for virtual participants to share their information with their physical counterparts: "*I couldn't really involve myself in, I could just usually find those tips, but* […*didn't know*…] *how to get them across* […*to the physical space*…]" (P9). The node users also had to choose between partaking in the physical task or corresponding with the virtual users to keep them involved.

Many participants expressed their concerns with having to use the whiteboard to consolidate their thoughts, resulting in issues such as confusion and annoyance: "*But I have to…go to whiteboard, see the task, come out of whiteboard, come out the other area, check it, I think I found it very tiresome*" (P1). Whilst the whiteboard had technical limitations that would have contributed to this annoyance and confusion, the placement of task-related information being only in the virtual space could have contributed more to the overall negative user experience. Therefore, the placement of task-related information, whether in the virtual and/or physical space, should be considered. This also occurred with other task-relevant information such as the videos for the video analysis task: "*There were two videos that we were supposed to watch and then come together, so the different speeds of people watching a video and then going back, sort of delayed that task*" (P6). A challenge identified here is where to place information for the most effective use by all collaborators. Simply replicating information in virtual and physical spaces seems inefficient. However, the interview feedback suggests that an imbalance in the location of information is equally frustrating to users.

IV. Conclusions and Future Work

This study has identified some of the advantages and challenges of collaboration in a BR environment based on a case study in higher education. The themes identified from the interviews and accompanying network analysis provide a starting point for the human-centered design of novel BR systems, from which user requirements can be developed. These relate to the affordances of BR spaces, communication across BR spaces, the design of BR 'features' and the emergent behaviours associated with these, the extent to which blending impacts on collaboration, and the placement of information in physical and virtual spaces within a BR environment. There will not necessarily be a single correct way to address these themes, and the design of BR systems will need to account for the context of use, which includes user characteristics, system goals, environment constraints, and technological considerations. There were also some limitations of the study. Firstly, the use of a 2D virtual space may have limited the capability of users compared to a 3D space. Conducting the study with a 3D space would have helped with participant immersion and presence which may have then translated to the collaboration in their group such as members being more involved. However, this would have also increased the complexity of the system and potentially increased the gradient of the learning for participants. Alongside this, increasing the variety and types of tasks within the seminars may have been beneficial in providing more insight into different forms of collaboration that could have occurred. Overall, this study offers an initial insight into the challenge of BR system design. Future work will explore the themes in more depth, with a view of creating guidance and user requirements to support the development of more human-centered collaborative systems.

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