AI as a Bridge Across Ages: Exploring The Opportunities of Artificial Intelligence in Supporting Inter-Generational Communication in Virtual Reality

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Inter-generational communication is essential for bridging generational gaps and fostering mutual understanding. However, maintaining it is complex due to cultural, communicative, and geographical differences. Recent research indicated that while Virtual Reality (VR) creates a relaxed atmosphere and promotes companionship, it inadequately addresses the complexities of inter-generational dialogue, including variations in values and relational dynamics. To address this gap, we explored the opportunities of Artificial Intelligence (AI) in supporting inter-generational communication in VR. We developed three AI probes (e.g., Content Generator, Communication Facilitator, and Search Engine) and employed them in a probe-based participatory design study with twelve inter-generational pairs. Our results show that AI facilitates inter-generational communication in VR by enhancing mutual understanding, fostering conversation fluency, and promoting active participation. We also introduce insights on desired AI features from participants and derive design implications for future AI-enhanced VR platforms, aiming to improve inter-generational communication.

CCS Concepts: • **Do Not Use This Code → Generate the Correct Terms for Your Paper**.

Additional Key Words and Phrases: Virtual Reality; Family; Social Interaction; Participatory Design

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1 INTRODUCTION

Inter-generational communication refers to the exchange of experiences and perspectives across generations, fostering a deeper mutual understanding and bridging the gap between different generations within a family [37, 78, 88]. Inter-generational communication plays a crucial role in nurturing emotional growth, enhancing self-esteem, and cementing familial bonds for younger members [11, 80, 89], while simultaneously providing older generations with essential social engagement and a cherished role in the family structure [17, 18, 50, 61, 70]. However, the rapid technological and cultural shifts of modern society pose considerable challenges to maintaining effective inter-generational communication. The disparity in cultural backgrounds, communication styles, and subtle emotional expressions, coupled with geographical distances, often hamper the flow and depth of these interactions [75, 83]. As such, the need to facilitate more active and effective inter-generational dialogue has become a pressing concern, especially within the HCI and CSCW communities.

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Recent research has seen the emergence of VR as a promising medium to support inter-generational communication. This tool offers unique affordances, such as customizable avatars, immersive virtual environments, and a sense of co-presence, which have shown promise in fostering more relaxed, equal, and emotionally fulfilling inter-generational interactions [5, 30, 47, 85]. Studies also showed that communication via VR could improve the overall quality of life for older people while decreasing the caregiver burden of their younger generations [2, 30]. While previous research has explored various aspects of VR, they often focused on predefined features and specific usage contexts [2, 30, 48, 85], not fully addressing the complexities of inter-generational dialogue, such as differing values, generational hierarchy, evolving emotional states, or relational dynamics (e.g., conflict management) [19, 83].

Recognizing these gaps, our work explores the integration of AI into immersive environments to enhance dynamic inter-generational communication. Previous research has highlighted AI's potential in facilitating inter-generational dialogue in non-immersive settings [35, 36, 91]. These studies revealed that AI could comprehend and respond to conversations in real-time, offering a unique opportunity to navigate the intricate and evolving dynamics of inter-generational communication, such as providing context-related photos to foster reminiscence [35, 36, 91, 92]. Despite these promising findings, there is still a limited understanding of how AI can be specifically designed to support such communication within VR environments. Immersive environments in VR provide AI with a flexible platform for presenting diverse outputs (e.g., text, audio, image, 3D model, etc.) through the use of interactive avatars, dynamic visualizations, and adaptable virtual spaces [12, 25, 28, 53, 69]. This could potentially transform current inter-generational interactions. Motivated by this possibility, we were compelled to investigate our first research question, **RQ1: how could AI be leveraged in VR to support inter-generational communication**?

Additionally, AI's involvement in inter-generational dialogue has the potential to affect the dynamics of family interactions and the way different generations coexist [33, 92]. Therefore, it is important to understand the desired interactions with AI in VR (e.g., methods for AI assistance invocation, and roles that AI should play), which can assist future researchers in developing suitable AI features tailored to inter-generational contexts. This inspired us to explore our second research question, **RQ2: How would two generations prefer to interact with AI features to support their communication in VR?**

Building on previous research that demonstrated the effectiveness of technology probe-based participatory design in eliciting user feedback and identifying opportunities in emerging technologies, such as the older adults' perceptions of the Internet of Things technologies [63] and AR for inter-generational storytelling [48], we adopted a similar methodology. We developed three kinds of AI probes (e.g., Content Generator, Communication Facilitator, and Search Engine) and conducted a probe-based participatory design study with twelve inter-generational pairs (including family relationships like grandparent-grandchild, parent-child, uncle-niece, etc.) to uncover the effectiveness and user expectations of AI in supporting inter-generational communication in VR environments. Participants first tried out these AI probes to inspire them to think about the possible ways in which AI could enhance their communication in VR. They then participated in a co-design workshop to brainstorm and design desired AI features to assist their communication.

Our findings illustrate the multifaceted advantages of AI in supporting inter-generational communication within VR. Drawing from the outcomes of our observation and participatory design workshop, participants leveraged AI to 1) foster their mutual understanding by generating visual representations of dialogue content and providing clearer explanations of era-specific terminology or objects; 2) enhance their conversation fluency by intervening in real-time to prevent awkward silences, maintain conversation coherence, and manage potential conflicts; and 3) promote their active participation by ensuring balanced dialogues and creating content-specific scenarios. Our results also showcase participants' preferences and insights on how AI features should be designed to foster comfortable and effective inter-generational communication experiences. In sum, we make the following contributions:

- Our study advances the understanding of AI in promoting inter-generational communication within immersive VR environments. We demonstrate AI's effectiveness in enhancing mutual understanding, improving conversational fluency, and encouraging active participation, highlighting its role in bridging generational gaps in VR interactions.
- Drawing from participatory design outcomes, we introduce participants' insights into customizing AI features to address specific communication needs in inter-generational interactions, as well as provide design implications for future researchers and developers to create more practical and meaningful AI-based VR platforms.

2 RELATED WORK

2.1 Benefits and challenges of inter-generational communication within a family

Inter-generational communication involves the exchange of information, ideas, beliefs, and feelings between individuals from different generations. Inter-generational communication within families (i.e., connection across generations like grandparents, parents, and children) is particularly beneficial [37, 78, 88]. On one hand, engaging in close inter-generational communication supports the growth and emotional development of younger family members, enhancing their self-esteem and deepening familial bonds [11, 80, 89]. On the other hand, it is crucial for older generations, providing them with valuable social engagement and reducing feelings of isolation [17, 18, 50, 61, 70]. This helps in maintaining an active and cherished role within the family dynamic. Thus, close inter-generational communication not only bridges the generational gap but also enriches the family as a whole, fostering a deeper understanding and appreciation of each generation's unique contributions [42, 72].

However, maintaining successful inter-generational communication is challenging in today's society, which is characterized by rapid technological and cultural shifts. First, while people have a strong need and desire to stay connected with their families to share recent life events, two generations find it difficult to achieve mutual understanding due to disparate cultural backgrounds, including distinct values, beliefs, and communication styles [58, 79]. This often leads to misinterpretations and conflicts in their exchanges, as well as reducing active engagement during conversation [59, 65].

Second, the generational hierarchy often results in the younger generation demonstrating over-accommodations towards the elderly [38]. Over-accommodation refers to the excessive or inappropriate adjustment of one's communication style, language, or behavior to cater to another person's perceived needs, such as continuously listening without interrupting. Although these actions are well-intentioned and display respect for the older generation, they frequently lead to miscommunication, a lack of genuine connection, and frustration among young people [26, 87].

Third, the subtlety of emotional expression between two generations hinders successful inter-generational communication, especially in countries with Eastern cultures [39, 76]. For example, older adults may express concern or affection through actions or indirect language rather than direct verbal expressions, such as providing unsolicited advice or preparing meals, instead of explicitly saying 'I care about you.' Younger generations, accustomed to more direct communication, might misinterpret these gestures as overbearing or unnecessary interference, rather than recognizing them as expressions of love and concern.

Additionally, geographical distance between family members often impedes intimate inter-generational communication [23, 29]. While audio-visual tools like audio or video calls enable remote connections, they do not always provide enough emotional support to give a feeling of closeness and intimacy. Therefore, further study on how to facilitate more active and effective inter-generational communication is warranted by HCI researchers.

2.2 VR for supporting inter-generational communication

Previous works in the HCI field have leveraged VR to support inter-generational communication [2, 30, 48, 85]. These studies demonstrated that three affordances of VR can support communication between two generations. First, VR allows users to represent themselves via customizable avatars. Such representation affects their perceptions of each other and blurs the generation gaps, thereby fostering a more casual and equal communication experience than in reality [85]. Second, users could engage in various activities in a virtual environment, which stimulates more topics for them to keep their conversations flowing [2, 30, 84, 85]. Third, VR's immersive environment offers the sense of co-presence for two generations to achieve a degree of companionship [1, 47], which is important for maintaining close emotional connections. Researchers also showed that using VR as a long-term communication tool improved the overall quality of life for older people while decreasing the caregiver burden of their younger generations who live far away [2].

While previous studies have demonstrated the potential of VR in facilitating inter-generational communication, their emphasis has predominantly been on utilizing predefined features to meet user needs within specific communicative contexts. For instance, Wang's and Hoeg's works explored the design of collaborative activities (e.g., tandem biking, co-learning) in VR for two generations [30, 84]. Wei et al. investigated the design of avatar appearances in VR to facilitate their communication [85]. However, these predefined designs fall short of addressing the myriad complexities inherent in inter-generational dialogue, such as navigating differing values, generational hierarchy, and the evolving nature of users' conversational content and emotional states [26, 58, 79, 87]. Therefore, this work aims to explore how to design a dynamic VR environment that could effectively address the challenges present during inter-generational communication in VR.

2.3 Integrating AI into inter-generational communication within VR environments

Previous research has shown that AI has the potential to moderate inter-generational communication since it can understand users' dialogue content and emotions in real-time, and intervene accordingly [7, 92]. Several studies have leveraged AI to support inter-generational communication in non-immersive environments [33, 35, 36, 91]. These studies used AI to provide context-related photos to arouse reminiscence and foster conversation [35, 36], generate story-related questions to enhance learning outcomes [22, 91], and answer users' questions to improve the collaboration efficacy [45]. Given these advantages, AI has been used to support various inter-generational activities such as storytelling [35, 91], co-reading [81], co-writing [45], and co-coding [21].

Despite the promising potential of AI in enhancing inter-generational communication, its integration into immersive VR environments remains under-explored. Unlike non-immersive tools that offer limited interaction (e.g., text-based or speech-based agents [92]), immersive environments present a unique opportunity to leverage various advanced outputs of AI to enhance communication, such as interactive and responsive virtual avatars, dynamic 3D visualizations, and adaptable virtual spaces [12, 25, 28, 53, 69]. Such features open new avenues for supporting communication between different generations. Nevertheless, prior studies also indicated that AI's involvement in inter-generational dialogue could potentially affect the dynamics of family interactions and the way different generations coexist [81, 91, 92]. Therefore, it's important to understand how AI can be leveraged in VR to support inter-generational communication and how two generations prefer to interact with AI features to support their communication. Such understanding could help future researchers and developers create more practical and meaningful AI-based VR platforms. To fill in these gaps, we employed a probe-based participatory design approach to explore the effectiveness and user envisions of AI in enhancing inter-generational communication in VR.

2.4 Technology probe methodology

A technology probe study is an innovative research methodology primarily used in the fields of HCI and CSCW [31, 32, 48, 63]. This method typically offers fundamental functionalities of specific emerging technology, enabling users to explore and understand their interactions with these innovations [32]. The primary purpose of a technology probe study is to inspire and provoke responses from users, shedding light on user needs, desires, and technological possibilities, rather than to test a specific hypothesis or to refine a product for real-life use. This is particularly valuable in the early stages of technology development, where understanding the user experience is crucial [48, 63].

Prior work has shown the feasibility of the technology probe study in identifying opportunities of emerging technology in inter-generational communication, such as AR [48] and VR [85]. By observing how participants use and adapt to the technology, these studies identify unforeseen opportunities and challenges, leading to more user-centered design decisions. Therefore, in this work, we adopted the technology probe study method to explore AI's possibilities for facilitating inter-generational communication in immersive environments and answering our two RQs.

3 METHOD

To answer our RQs, we first designed and implemented AI probes, and then conducted a probe-based participatory design workshop to elicit perceptions and envisions of AI designs from participants. For simplicity, in the rest of this paper, the older generation and younger generation are abbreviated as OG and YG respectively (e.g., P1-YG means the younger generation in pair 1).

3.1 Probe Design and Implementation

We designed and developed three types of AI probes for participants to experience, including **Content Generation** (i.e., image generation, 3D object generation, and scene generation), **Communication Facilitator** (i.e., chat facilitator and emotional visualization), and **Search Engine**, as shown in Figure 1. The goal of providing these probes was to gain a firsthand understanding of how inter-generational participants leverage AI in their communication, as well as inspire them to envision future usages and express their preferences for AI-enhanced communication within VR environments [32]. In this section, we introduce the design considerations and implementation details of each AI probe.

3.1.1 Content Generation. Previous literature suggested that visualizing abstract concepts can improve understanding and accessibility across different generations, potentially bridging knowledge gaps [4]. Current AI technologies enable users to generate content through simple verbal descriptions, thereby enhancing the ease of incorporating content generation into everyday conversations [46, 64]. In this study, we developed images, 3D objects, and scene generation.

Image generation: This feature is activated when users click a button and provide verbal descriptions of an image. The system then generates the image based on these voice prompts and displays it in front of two users. They can manipulate these images – grabbing, moving, or rotating them, as illustrated in the first image of Figure 1. If the generated images do not meet the users' expectations, they can be discarded by dragging them into a virtual trash bin. For implementation, we used Azure AI Speech for voice transcription [1] and DALL-E2 for image generation [2].

[1]https://azure.microsoft.com/en-us/products/ai-services/ai-speech
[2]https://openai.com/dall-e-2

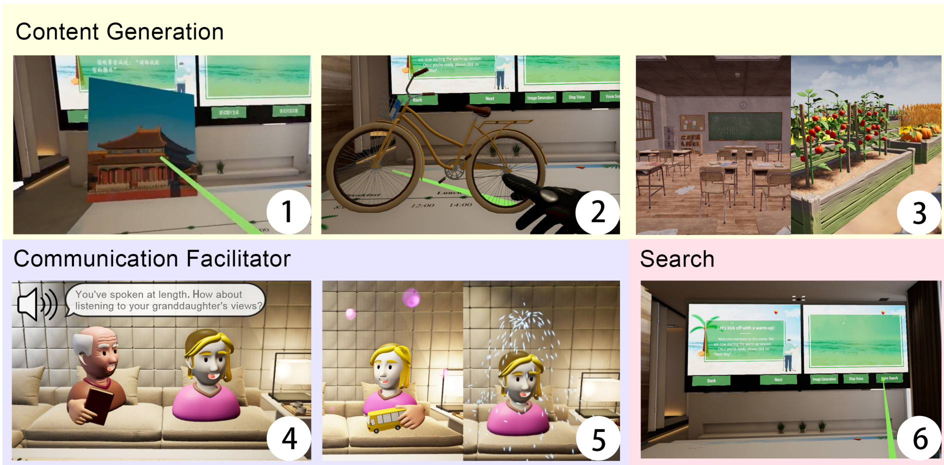

Fig. 1. Illustrations of the AI probes used in our study. (1) Image generation: it generates images based on verbal descriptions provided by users. (2) 3D Object generation: it creates virtual 3D models according to users' verbal descriptions. (3) Scene generation: the virtual environment automatically switches based on the content of the conversation. (4) Chat facilitator: it intervenes verbally to balance conversations when one party dominates, and offers potential conversation topics through voice prompts during awkward silences. (5) Emotion visualization: analyzing the emotional tone of chat content, it displays bubble effects for positive emotions (left) and rain effects for negative emotions (right). (6) Search: users press the button to input voice-based queries and receive spoken answers in response to their inquiries.

3D object generation: Considering the rendering time and computing costs of 3D object generation from text, we opted to provide users with a selection of pre-generated 3D objects relevant to their tasks, such as various vehicles (bus, taxi, etc.) for the first task and assorted stationery items (vintage chair, ruler, pencil case, printer, etc.) for the second. For implementation, we used Point-E to generate 3D models from text [60]. Additionally, we implemented a keyword detection technology that automatically activates this feature whenever users mention specific terms from our curated list. Upon detection, these 3D objects materialize in front of the users.

Scene generation: Similar to 3D object generation, we provided pre-created virtual scenes pertinent to the tasks, such as a living room or a farm for the first task and both a new and an old classroom for the second. These scenes are activated through keyword recognition. The scenes were developed using Set-the-Scene [14].

3.1.2 Communication Facilitator. Integrating an AI coordinator to monitor dialogue and offer timely interventions has the potential to enhance communication efficiency and foster engagement [92]. To examine the effectiveness of AI coordinators in inter-generational contexts, we developed the chat facilitator and emotional visualization.

Chat Facilitator: This feature provides verbal interventions in a conversation. We employed Large Language Models (LLMs) to detect silences (i.e., no one speaks for more than 10 seconds) and imbalances (i.e., one party speaks continuously for over a minute while the other remains silent), and utilized prompt engineering [40] with ERNIE Bot [3] to provide appropriate voice suggestions to mitigate these issues. For example, if one party dominates the conversation, the Chat Facilitator might suggest, "How about listening to the other's opinions?"

[3]https://yiyan.baidu.com/

Emotional Visualization: This feature introduces visual interventions during conversations to represent users' emotions. We employed keyword monitoring to detect positive (e.g., 'happy', 'excited') and negative emotions (e.g., 'sad', 'tired'). Subsequently, we incorporated specific visual effects that corresponded with these emotions. For example, the rain effect was chosen to express their negative emotions, as rain is usually associated with sadness. Conversely, bubble effects were used for positive emotions, reflecting their joyful connotations, as shown in the fifth image in Figure 1.

3.1.3 Search Engine. **Search Engine** was built on Large Language Models. Users invoke this function by clicking a button, as depicted in the sixth image of Figure 1. Participant verbal queries were processed by a search engine, with responses displayed as text on the screen and simultaneously vocalized using Azure AI Speech. Additionally, participants had the option to halt the audio playback at any time by activating the "Stop Speech" button. The search engine functionality was developed using ChatGPT-3.5 [4].

3.1.4 System Implementation. The goal of our system design was to integrate all the AI technology probes into a single, user-friendly VR application for inter-generational communication. We developed the system using Unreal Engine 5.1.1 [5]. The initial VR environment featured a cozy living room setup, complete with a sofa, a coffee table, two display screens, and typical household decorations. The two screens in front of the users displayed different information: the left screen displayed task instructions, while the right screen offered an interactive interface for invoking AI-driven search and image generation functions. Our system supports remote VR communication through UDP (User Datagram Protocol) for real-time interaction and synchronization of virtual items and scenes across both users' interfaces. Additionally, we equipped the system with a camera to document participants' behaviors and interactions within the VR environment.

3.2 Participants

We recruited 12 pairs of participants (24 in total) from various backgrounds (e.g., education level, occupation). The older and younger participants in each pair had diverse relationships (6 pairs were grandparent-grandchild, 2 pairs were parent-child, and 4 pairs were other forms of kinship, such as uncle-niece). The YG participants were aged 15 to 30 ($M = 20.6, SD = 5.2$) and the OG participants were aged 55 to 78 ($M = 63.2, SD = 6.0$). All participants met the inclusion criteria, which were no major medical illnesses, no history of mental or neurological abnormalities, and no sensory impairments. Most participants (OG: n=9, YG: n=12) had experience using AI-based products, including voice assistants (e.g., Siri or Tmall Genie), and generative AI applications (e.g., ChatGPT or ERNIE Bot). Most participants (OG: n=11, YG: n=9) had no prior experience with VR. Before the start of the study, written informed consent was obtained from each participant, with the study purpose and task. All participants were informed of their right to withdraw from the study at any time, although no participants chose to do so. All participants were given payment at the end of the study. Detailed background information about the participants is shown in Table 1. For simplicity, grandparent and grandchild are abbreviated as GP and GC respectively.

3.3 Procedure

Our workshop included three parts as shown in Figure 2. The session lasted an average of 1.5 hours. The study was conducted in a laboratory setting. Two participants were in the same room, with

[4] https://chat.openai.com/
[5] https://www.unrealengine.com/en-US/

Table 1. Demographics of the participant pairs

Pair ID	Relationship	Age (OG-YG)	VR experience (OG-YG)	AI experience (OG-YG)
1	GP-GC	61-15	No-No	No-Yes
2	kinship	61-22	No-Yes	Yes-Yes
3	kinship	60-25	Yes-No	Yes-Yes
4	Parent-Child	55-20	No-No	Yes-Yes
5	Parent-Child	60-30	No-No	Yes-Yes
6	GP-GC	78-26	No-No	No-Yes
7	kinship	60-25	No-No	Yes-Yes
8	GP-GC	63-15	No-No	No-Yes
9	GP-GC	68-16	No-Yes	Yes-Yes
10	kinship	61-22	No-No	Yes-Yes
11	GP-GC	62-16	No-Yes	Yes-Yes
12	GP-GC	70-15	No-No	Yes-Yes

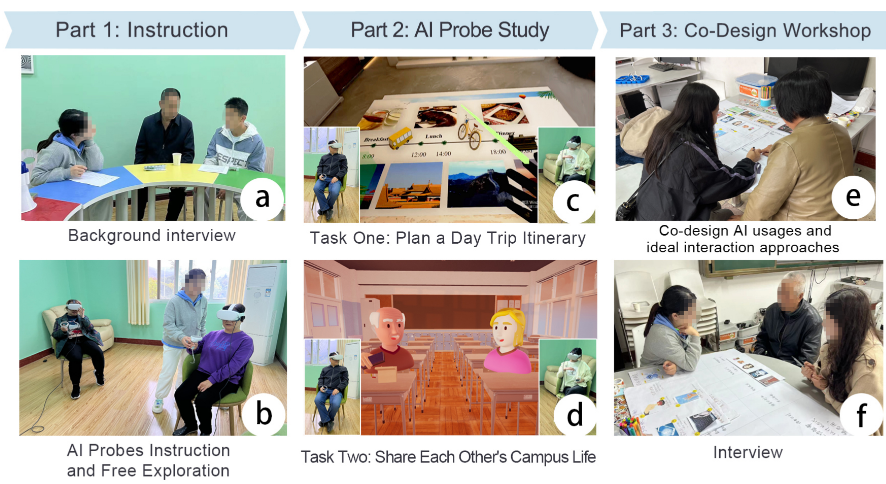

Fig. 2. The user study process is structured into distinct parts, each represented by a column. The session began with a background interview (a), followed by a comprehensive tutorial on VR operations and AI probe usage (b). Subsequently, participants engaged in an AI probe study, initially focusing on planning a day's itinerary (c), then shifting to sharing stories about their campus life (d). The session culminated in a co-design session, encompassing both brainstorming activities (e) and thorough in-depth interviews (f).

two moderators present to assist in the experimental process. This study received approval from the author's institutional ethics review board.

3.3.1 Part 1: Background Interview and Instruction. Our study began with an introduction of the study and tasks, along with a background information interview (e.g., age, relationship, occupation, communication frequency, VR experience, and AI experience). Considering that most participants had no prior experience with VR, we started by teaching them the basic operations of VR (e.g., UI and virtual object manipulation). We then introduced the participants to our three types of AI probes, explaining the interaction methods for each probe. After a thorough presentation of the AI probes' functionalities, we encouraged the participants to independently try out each feature, ensuring they could use and understand them smoothly. We also observed their interaction process during the tutorial and asked for their feedback on the experience.

3.3.2 Part 2: AI Probe Study. After verifying participants' comprehension of the AI probes and VR manipulation, participants completed the following tasks: 1) Plan a day itinerary and 2) Share each other's campus life. These two tasks represented the two most common activities in inter-generational communication in everyday life: co-negotiation and life-sharing [24, 49]. This part was designed to be completed within an approximate timeframe of 30 minutes.

Task 1: Plan a day itinerary. The goal of this task was to stimulate discussion and decision-making between the two participants under a fixed topic. In the task, two participants collaborated to complete a day trip schedule (e.g., choosing and determining meals, attractions, transportation, etc.). They were provided with a blank schedule planner with a timeline marking several points in the day, which they were required to fill in by generating pictures or 3D objects, as shown in Figure 2(c). Participants were free to use any of the AI probes to complete the task.

Task 2: Share each other's campus life. This task encouraged participants to communicate their thoughts and exchange narratives about experiences unfamiliar to the other generation. Specifically, two participants took turns sharing stories of their campus lives. Throughout this exchange, interruptions for clarification or engagement were permitted, encouraging interactive dialogue. Participants did not have specific goals to accomplish and could stop the task at any time. During the storytelling process, participants could use the AI probes freely to support their communication.

3.3.3 Part 3: Co-design workshop. Finally, we conducted a co-design session with participants. First, a pair of participants engaged in brainstorming sessions, discussing scenarios where they could use the AI probes, and reflected on ways to enhance AI design to better suit these scenarios. Following this, we conducted in-depth interviews with the participants to gather detailed insights about the outcomes of their discussion to extract comprehensive insights, including their ideal AI scenarios, preferred interaction strategies, and the expected visual representations of AI. Additionally, we encouraged participants to disclose any challenges they faced during the AI probe study and to offer suggestions for enhancements in AI design.

3.4 Data Analysis

Our data included video recordings of the sessions. The video recordings were first transcribed by DeepL [6], which was then checked by the first authors for accuracy. We first established two main themes according to our two RQs: the potential use of AI in facilitating inter-generational communication in VR, and the envisions of two generations on future AI interactions. After identifying the key themes, all co-authors first read three random transcripts and formed their initial codebooks [15, 16], and then employed Affinity Diagramming to sort and integrate the coded information to form subthemes under each primary theme [10]. For example, when participants discussed their future envisions for employing AI in specific communication scenarios, we categorized these discussions under the main theme 'How could AI be leveraged in VR to support inter-generational communication'. Then, we identified a sub-theme "AI could offer fair interventions to manage conflicts," which emerged when phrases like "conflict mediator," "AI's fairness and impartiality," and "timely intervention to interrupt arguments" were frequently mentioned in their responses. After coding and forming subthemes of three random transcripts, we made comparisons between our codes to identify any discrepancies and discuss possible revisions, until reaching a final agreement. Once a consensus on the coding framework was reached, each co-author applied the refined coding strategy to the rest of the transcripts independently. This process yielded an inter-rater reliability score of 92.3%, signaling a high degree of concordance among the authors in the coding decisions and category assignments [27].

[6] https://www.deepl.com

4 FINDINGS

Our results demonstrate how AI could support inter-generational communication in VR among the participants. In this section, we present the key findings of our two RQs.

Table 2. Key Findings of RQ1: How AI can be leveraged in VR to support inter-generational communication. The examples in the table were collected from observations in the AI probe study and participants' envisioned applications of AI in co-design workshops. Envisioned scenarios were distinguished with an asterisk (*).

Key Findings	AI capabilities	Examples
Leverage AI to enhance mutual understanding	• Visualizing conversation content to better exchange ideas and thoughts	• Participants used Content Generation to generate an image of 'chemistry laboratory' to introduce their dream profession; generate daily tools for imparting life skills to each other*
	• Explaining era-specific vocabulary or objects to better share knowledge	• Participants used Search Function to explain 'involution (nèi juǎn in Chinese)'; used Content Generation to introduce machinery from the OG's era
Leverage AI to foster conversation fluency	• Providing potential topics and activities to avoid awkward silences	• Chat Facilitator suggested *"Could you share something about your closest classmates?"* when the conversation falls into silence
	• Assisting pairs in maintaining coherent and in-depth conversations	• Participants could revisit topics they have discussed before by asking the Chat Facilitator*
	• Offering fair interventions to manage conflicts	• Chat Facilitator could suggest a temporary cool-down or offer objective and authoritative solutions*
Leverage AI to promote active participation	• Balancing the participation of two generations in conversations or collaborations	• Chat Facilitator suggested *"How about listening to the other's opinions?"* to notify the talkative person
	• Providing content-specific spaces to offer an immersive conversation experience	• Content Generation switched the VR space to an old classroom when the OGs were reminiscing about their campus experiences
	• Modifying the virtual environment based on the pair's emotion to maintain positive communication experiences	• Emotional Visualization could provide a bright and colorful environment in VR when the conversation is sad; offer vibrant and dynamic elements when the conversation becomes dull*

4.1 RQ1: How could AI be leveraged in VR to support inter-generational communication?

We found that AI supported inter-generational communication in VR in the following aspects: enhancing mutual understanding, fostering conversation fluency, and promoting active participation. The key findings are summarized in Table 2.

4.1.1 Leverage AI to enhance mutual understanding between two generations. Mutual understanding refers to comprehending each other's thoughts to bridge generational knowledge gaps and enhance empathy. We outlined two benefits of how AI could support mutual understanding.

AI could visualize conversation content through the generation of virtual images, 3D objects, and scenes in VR, enabling users to share and comprehend others' ideas and thoughts more easily and intuitively. During the AI probe study, participants used the Content Generation to create images and 3D objects to introduce concepts that were unfamiliar to their partners. For example, when the older participants shared stories of their past school experiences, all of them tried to generate scenes or objects by saying *"Please take us back to my childhood classroom,"* (P4-OG) or *"Show me an old, dilapidated stool made of wood"* (P2-OG). They then continued telling the story using the generated items or spaces as references. Similarly, when younger participants described their current jobs or future aspirations to their elders, they often generated photos, such as *"a chemistry laboratory"* (P4-YG) or *"a flag bearer raising a flag"* (P1-YG). They indicated that incorporating visual aids would enhance clarity and prevent misunderstandings or confusion.

In the Co-design Workshop, participants envisioned that they could use Object Generation to generate daily tools in VR for imparting life skills to each other remotely, enhancing inter-generational knowledge transfer. On the one hand, the older generations could effectively learn how to use the electronic tools from younger generations by generating these tools and practicing in VR environments. As the P6-OG indicated, *"my daughter often brought me smart home appliances like robotic vacuum cleaners to ease my workload. However, we struggled to learn and use these products and often underutilized or abandoned them when she was not home."* They thought that using voice or video calls to ask for help was inefficient and often failed to resolve the issues. However, they believed that generated 3D objects in a VR environment could address this gap since they could repeatedly try and practice these skills without the fear of real-world consequences associated with failure. Similarly, younger participants also indicated their need to seek advice from their elders on life skills, such as *"learning grandma's signature dish"* (P6-YG). They believed that VR Content Generation could effectively aid them in learning life skills hands-on from their elders.

AI could help explain era-specific vocabulary or objects by offering clear explanations and visual aids in VR. Era-specific vocabulary or objects often reflect specific cultural contexts, events, or trends, which are familiar to one generation but may be completely alien to another. Participants said that AI played a crucial role in offering clear and neutral explanations, helping two generations to grasp the meanings and origins of these terms. For instance, P7-YG mentioned the term "involution (nèi juǎn in Chinese)" when sharing her college experience, which confused the older listener. To clarify, she employed the Search Engine to offer a detailed background of the term. They appreciated the clear and straightforward explanations that AI offered. P7-YG indicated that *"It offered cultural and sociological implications, current relevance, and examples of its use in various contexts, far surpassing my explanations"*.

Older participants also used the Search Engine and the Image Generation function to introduce their era-specific objects to the young participants. During the discussion about campus life, P4-OG reminisced about using a mimeograph machine to produce exam papers, noting how it often left hands dirty. He generated a picture of the *"mimeograph machine"*, and acknowledged that AI provided a more effective explanation than he could. P4-YG also favored AI's clear explanations over his father's more didactic style, noting how the AI avoided veering into patronizingly educational advice, unlike the elders who would typically segue into urging harder work due to improved material conditions.

4.1.2 Leverage AI to foster conversation fluency between two generations. Based on our observations and workshops, we identified three potential ways in which AI could facilitate conversation fluency.

AI could comprehend user dialogues and provide potential topics and activities to avoid awkward silences and keep the conversation flowing. During the study, eight pairs of participants encountered silence during their interactions. For example, after P1-YG stated he was doing well in school, he fell silent. P1-OG, too, did not make any further inquiries or continue the conversation. Sensing this, the Chat Facilitator intervened with a voice suggestion, *"Could you share something about your closest classmates?"* Participants appreciated the mediator from the Chat Facilitator and felt it provided an active communication experience. As P1-YG highlighted, *"When discussing my school life with my grandma, I was unsure about her interests, leading me to briefly touch on basic information before stopping. However, this doesn't mean I lacked the desire to chat with her. The facilitator suggested the potential topics that we could discuss. I appreciated that."* Participants indicated that their differences in experiences, knowledge, and interests often led to limited topics for discussion and awkward silences in conversation. They hoped that the AI could suggest topics of mutual interest based on their personalities and life backgrounds, combined with the content of their previous conversations.

In addition to suggesting potential topics for discussion, P9-YG suggested that AI could also recommend activities for them to engage in next. For instance, watching a movie related to their conversation topics or participating in psychological exercises together could be beneficial.

AI could assist pairs in maintaining coherent, in-depth conversations by revisiting and summarizing previous conversation content. Participants expressed that they often find themselves veering off-topic in conversations and then struggling to recall what the original topic of discussion was. This not only hindered the smooth progression of the conversation but also led to feelings of frustration for older participants. As P2-OG mentioned, *"I keep forgetting what I was about to say, or repeating the same thing several times... Sometimes it frustrates me because I would start thinking it's probably because I'm getting older."* They suggested that the AI could assist users in revisiting topics they discussed before, enabling them to sustain coherent and detailed discussions.

Several participants also envisioned that AI could help summarize their discussion content to automatically formulate plans. They shared with us that they often engaged in casual conversations to make plans, such as *"discussing what dishes to cook for dinner, what groceries to buy, how to decorate their garden, and even planning their trips for the next day"* (p10-OG). Their discussions were usually informal, unlike structured meetings in a company where someone might take notes. This casual nature often led to inefficiencies since they tended to forget the details soon after. They believed that AI could be helpful by recording their conversations in real time and summarizing the key points of their plans.

AI could offer fair interventions to manage conflicts, maintaining a harmonious atmosphere in communications. During the co-design workshop, participants expressed the idea of employing AI as a mediator in their daily conversations, particularly to help mitigate conflicts. In this case, AI could intervene in conversations by suggesting a temporary cool-down or offering objective solutions. For instance, in task 2, P8-OG opined that today's campus life is happier than before, but P8-YG countered, citing increased academic pressure now. This led P8-OG to criticize P8-YG for lacking resilience and endurance, causing unpleasantness in their conversation. P8-YG suggested that *"this was a moment where AI could intervene. It could be beneficial to prevent the argument from escalating by offering advice, thereby maintaining a harmonious atmosphere"*.

Intriguingly, several participants expected they might prefer AI over human coordinators for resolving inter-generational conflicts. This preference stemmed from their perception of AI as being neutral and unbiased, unlike humans who could be influenced by emotional attachments or social connections. For instance, P8-YG remarked, *"When I have conflicts with my grandfather, I'd rather listen to AI than my parents or grandmother because my parents always side with my grandfather,* *and my grandmother with me. I feel that none of them can persuade us rationally and impartially."* This comment underscored the perceived impartiality of AI in conflict resolution.

Despite high expectations for AI's role as a conflict mediator, participants also voiced concerns about its ability to grasp the context and subtleties of their conflicts. As P11-YG mentioned, *"Sometimes, a simple remark from my dad can make me angry. This is because there are long-standing sibling rivalries or past incidents that substantially impact the dispute. I feel that AI might not understand the root of my anger, so I would doubt it can offer comforting advice or suitable solutions."* Participants acknowledged the complexities inherent in each family, posing a substantial challenge for AI in accurately understanding conflicts and responding suitably. They expressed apprehension that an inappropriate AI intervention could potentially worsen the argument.

4.1.3 Leverage AI to promote active participation between two generations. We identified three reasons why AI could make inter-generational communication in VR more active.

AI could balance the participation of two generations by providing real-time interventions. During the study, AI was activated in seven pairs of participants to balance their conversation. For example, in Task 1, younger participants may independently craft travel plans without seeking advice from their older participants. In this instance, the Chat Facilitator provided suggestions using a voice prompt: *"Let's have both sides discuss together the places you would like to visit."* They appreciated the reminder of AI and thought it made them attentive to the other's feelings during the conversation. As P3-YG mentioned, *"I got so wrapped up in making the plans that I forgot to discuss the plans with them. I might have ended up doing the whole schedule by myself if it weren't for the AI reminding me."*

Conversely, in Task 2, the older participants often engaged in extended storytelling, ignoring whether the younger listeners were interested. Although the younger participants generally refrained from interrupting the storytelling, believing it to be impolite and disrespectful towards the older generations, they indicated *"having to listen all the time drains me. It made me feel bored and I found myself zoning out"* (P6-YG). They thought that AI could serve as an effective mediator in this context because its non-living and neutral nature made the intervention less likely to offend older generations, thus ensuring the harmonious progression of the conversation. The older participants also indicated their welcoming of AI's reminder. As P5-OG described, *"I probably didn't realize this problem because I was excited to tell my story at this time. I'm grateful for the AI's reminder. I think discussing with him together is much more enjoyable than just talking by myself."*

AI could provide content-specific spaces to offer an immersive environment and engage them in active conversation. Participants commended the benefits of switching the virtual scenes in VR according to their communication content. They thought that it provided an immersive communication experience that fostered a greater willingness to listen and share stories. Participants indicated that their current storytelling process was usually led by the older generations while the younger generations often lacked a sense of involvement and empathy. As P10-YG mentioned *"Sometimes, I get impatient listening to her youth stories because they're hard for me to relate to...However, I found her youth stories more engaging during VR experiences, as they make me feel like I'm reliving those moments with her."* They appreciated that AI could generate scenes in VR (e.g., an old family home, a childhood playground, or a meaningful location from the past) or 3D virtual items (e.g., agricultural tools or stroller) to enhance the storytelling experience and actively engage listeners in the storytelling process.

Additionally, participants envisioned that AI could provide active co-learning experiences by creating historical scenes and geographical landscapes mentioned in textbooks within VR environments. They indicated that co-learning was a common activity they engaged in at home, and AI could potentially benefit this activity by boosting learning interests and outcomes. For example, the P12-OG expressed that *"AI can help bring to life the scenes described in ancient poetry, allowing us to immerse ourselves in these landscapes witnessed by poets centuries ago in VR. I think it could deepen our appreciation and understanding of the poetry."* Participants also suggested that AI could help them to automatically *"dress up to resemble a local person from that era"* (P12-YG) to make them feel more engaged during the co-learning process.

AI could modify the virtual environment based on the pair's emotion to maintain positive communication experiences. During the VR experience, participants' pronounced emotions were visualized in real-time (e.g., rainy effects appeared when negative sentiments were detected and pink bubbles appeared for positive ones). Participants appreciated the visualization of their positive emotions and thought that *"it made me feel my uncle's joy, which in turn made me happier and more willing to discuss the topic further with him"* (P7-YG). They suggested that in addition to the visual effects we provided, AI could offer more engaging feedback to express user happiness, such as *"providing joyful background music, altering the surrounding environment, and making objects around them dance"*.

While most participants saw value in visualizing positive emotions to enhance the conversation atmosphere, they unanimously preferred not to exaggerate or display their negative emotions to others. As P9-OG mentioned, *"We don't want the VR world to show our bad moods. Imagine feeling down and suddenly there's a storm in the VR — that'd just make us feel worse. I think it's better if the VR environment could help us chill out and get our mood back on track when we're feeling low."* They suggested that if the conversation is serious or sad, the scene could transform into something bright and colorful, like a sunny park or a lively beach, to lift spirits. If the conversation becomes inactive or dull, the setting might shift to something more vibrant and dynamic, with interactive elements like playful animals, to re-energize the dialogue. Therefore, they could better engage in positive communication and maintain pleasure experiences.

4.2 RQ2: How would two generations prefer to interact with AI features to support their communication in VR?

Based on the co-design workshop, we synthesized participant suggestions for enhancing AI features for inter-generational communication. We first outlined their proposed interaction strategies concerning our three AI probes. Additionally, we discussed their expectations regarding AI's visual representation and its ability to accurately recognize different dialects.

4.2.1 Content Generation. Participants discussed their preferred methods for activating Content Generation in VR, as well as proposing their envisioned strategies to interact with this feature.

Activation method. Participants envisioned two kinds of activation methods, as shown in Figure 3. Generally, participants favored a manual, user-controlled approach to invoke the Content Generation for most scenarios (Figure 3(a1)). This *passive* method enables users to engage the AI as needed through buttons, voice commands, or gestures. Such control is essential for maintaining user autonomy and minimizing interruptions, especially during private or in-depth conversations. As P8-YG mentioned: *"It would be too dazzling if AI generated a scene wherever I was chatting. It made me feel like we were creating rather than chatting."*

Nevertheless, for specific situations like emotional downturns, participants saw the potential for a *proactive* Content Generation role (Figure 3(a2)). They noted that during intense emotions such as sadness or anger, they tended to become absorbed in their feelings, focusing on the emotions rather than seeking ways to alleviate or manage them. In these situations, participants appreciated the idea of proactive AI intervention. P11-OG stated that: *"when I become angry or sad during the conversation, I might not realize it myself or activate this function [Content Generation]. But I*

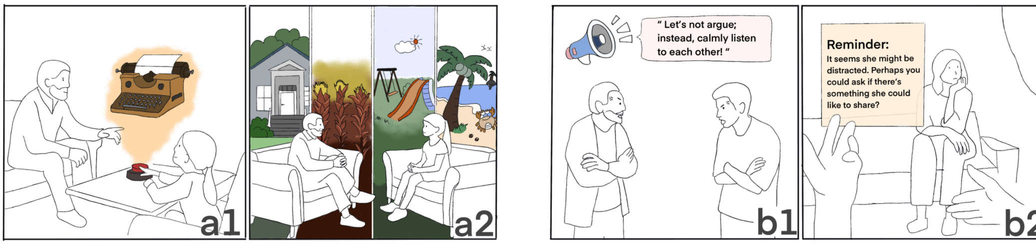

Fig. 3. Illustrations of participant-proposed interaction strategies for two AI Probes. For *Content Generation*, two activation methods are envisioned: a1) passive activation, which emphasizes user autonomy and aims to minimize interruptions; a2) proactive activation, where the virtual environment in VR dynamically changes in response to the user's emotions or conversation content. For the *Communication Facilitator*, two intervention strategies are proposed: b1) prompts visible to both parties involved in the communication; b2) private prompts designed to discreetly remind the user of their behavior.

think that beautiful scenery in VR, like the seaside or a forest, can regulate my emotions and ease the relationship between us."

Other suggestions. Participants offered additional suggestions for enhancing interaction with the Content Generation feature. First, participants expressed a desire for more accurate outputs from the Content Generation. Participants found that there were instances where the AI failed to meet expectations, largely due to its limited understanding of their backgrounds. For instance, when P4-OG requested the image of *"my childhood classroom,"* the AI struggled to discern the specific period of *"childhood"* or the architectural style of classrooms from that particular region and era. Therefore, they expected future AI could be developed to better understand their intentions.

Second, they proposed that the AI should be capable of creating virtual environments from provided photographs. This approach would yield more accurate and tailored virtual scenes, enriching the storytelling experience with enhanced immersion. As P12-OG mentioned, *"My verbal description might not be clear enough, but a photo can better convey the place I want to visit."*

Finally, participants recommended that the Content Generation feature did not need to initially generate highly detailed items or scenes. Instead, the AI should offer users the flexibility to customize 3D objects based on their preferences. This would allow users to design and refine their ideal virtual environments, tailoring the spaces to their specific needs and involving them more deeply in the creative process. P5-YG described this benefit: *"This would allow us to arrange furniture and decorate our home. I think this would lead to a much more interactive and engaging experience."*

4.2.2 Communication Facilitator. Participants emphasized the need for a more intricate design in determining the optimal approaches for the Communication Facilitator's intervention. This is critical because inappropriate interventions can disrupt their flow of communication, leading to an awkward atmosphere and potentially exacerbating conflicts. Based on the results of the co-design workshop, participants suggested two kinds of AI intervention strategies tailored to different scenarios.

The first potential intervention method is to display **prompts visible to both parties** (Figure 3(b1)). This kind of intervention could be beneficial for conflict management. Participants envisioned that when signs of potential conflicts are detected (e.g., *"frequent use of negative vocabulary, unusually loud volume, or a faster speech rate"* (P11-OG)), AI could intervene with prompts noticeable to both parties such as an audio announcement to suggest a cool-down period or provide an objective solution. As P11-YG mentioned, *"When conflicts arise, we may both be irrational and*

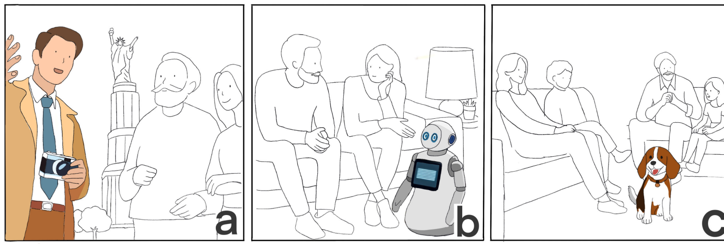

Fig. 4. Illustration of participants' suggestions for AI's visual representation: a) shows a realistic, context-appropriate AI appearance such as a tour guide describing the attraction. Participants indicated that such representations would be especially beneficial in VR-shared activities, enhancing immersion and providing convincing guidance; b) depicts an inanimate virtual agent as a robot. Participants believed that it reduces their concerns about privacy and authenticity, making them more suitable for private conversations; c) represents a friendly and cute pet as a virtual agent. Participants believed that such representations were effective in easing tension and adding humor to interactions.

may even say something hurtful to the other party". They believed that this direct and proactive strategy could effectively modify the communication atmosphere, prevent emotional escalation, and avert conflict deterioration.

Participants anticipated that AI could offer **private prompts** in situations where one party dominates the conversation or when there is an awkward silence (Figure 3(b2)). They suggested that AI could offer private prompts to the user causing the issue to gently remind them of their behavior. For instance, a discreet text prompt such as *"You've spoken at length; let the other person share their views"* could be displayed only in the dominant speaker's VR environment; Similarly, when one party discusses uninteresting topics for the other, a prompt like *"It seems that they don't want to talk about this. Try asking about their enjoyable moments at school."* could be shown to the speaker to encourage positive communication experiences.

Participants indicated that the private prompts, compared to cues visible to both parties, would maintain a positive conversation atmosphere and flow while preserving the dignity of the prompted user. Younger participants found this particularly valuable, as they might be reluctant to directly interrupt or express discomfort to older conversation partners, such as when the elderly overly dominated the conversation or broached unwelcome topics. P10-YG shared that *"there are times when elders bring up uncomfortable topics, like questions about my boyfriend or salary. I'd prefer the AI to subtly indicate my discomfort, rather than having to voice it myself. Visible prompts to both participants could be awkward in this scenario."* Older participants also saw value in private prompts, acknowledging that they sometimes did not realize the younger generation's disinterest in their topics. P9-OG stated, *"If I'm speaking excitedly, I might not realize that others aren't getting a chance to speak. I hope the AI can remind me discreetly."*

4.2.3 Search Function. For improved interaction with the Search Function, participants expected the AI to understand their inquiries in a more "human-like" manner, such as integrating their non-verbal cues or conversation context. It was observed that the AI occasionally failed to comprehend participants' inquiries during the study. A case occurred when P4-OG pointed at a photo of ancient buildings and asked AI, *"Where is this place?"* This action demonstrated a natural interaction style commonly used in real-life conversations. However, the Search Function struggled to grasp the implication of *"this"* in such scenarios and consequently failed to deliver relevant responses.

4.2.4 Visual representation of AI. Our study did not provide a specific visual representation for AI, yet participants felt that AI should have a visual form to indicate its presence in various communication contexts. They proposed three distinct types of visual representations, each suited to different scenarios, as shown in Figure 4.

First, participants suggested a realistic, context-appropriate AI appearance, such as a virtual tour guide or a teacher. Participants believed that such representations would be particularly effective in VR-shared activities, enhancing user immersion and providing convincing guidance. As P4-YG noted: *"A guide dressed in formal attire in a VR museum is more convincing than a dog or cat."* However, this realistic avatar, despite its effectiveness in providing immersive experiences for users, may hinder casual inter-generational conversation due to its strong and invasive presence as P6-YG commented: *"Such a strong presence of AI feels like it's listening in on everything we say, which is somewhat uncomfortable."*

The second proposed form was an inanimate virtual agent, such as a robot. Participants indicated that, in contrast to lifelike avatars, the non-human appearance of robots reduced their concerns about privacy and authenticity, making them more suitable for private conversations. Additionally, robots were seen as impartial, free from emotions or biases, and thus, ideal for conflict mediation. As P3-YG highlighted *"I feel more open to listening to the unbiased advice from the emotionless robots."*

Lastly, participants suggested friendly and cute virtual agents, like cartoon characters or pets, for their ability to create a relaxed and joyful atmosphere. This approach may mediate conversational dynamics, especially during awkward or silent moments between generations. Cartoon characters or cute pets were seen as effective in easing tension and adding humor to interactions. As P1-YG remarked, *"I prefer cartoon puppies as they feel like part of the family and their interactions are natural and unforced. Their cuteness makes me more receptive to their advice, making cartoon characters a more comfortable choice for receiving guidance."*

4.2.5 Need for dialect recognition. Participants highlighted a substantial limitation in AI's capability to recognize dialects, which they felt impaired their communication experience. This issue was particularly evident in China, where many older adults, especially those residing in rural areas or those with limited formal education, struggled with fluency in standard Mandarin. Our study revealed a strong preference among most participants for using local dialects when communicating with family members. However, to facilitate better understanding by the AI during the study, they were compelled to switch from their native dialects to standard Mandarin. This switch was perceived as a distraction, detracting from the natural flow of conversation. Therefore, participants suggested that incorporating dialect recognition into AI systems appears to be a pivotal step toward their broader acceptance and utility. As P6-YG noted, *"Although my grandparents and I can both speak Mandarin, conversing in our dialect fosters a deeper sense of comfort and intimacy. When we need to search for information mid-conversation, using dialect doesn't disrupt the flow and maintains the coherence of communication."* This insight underscores the potential of dialect-inclusive AI in enhancing user experience and fostering more natural, seamless interactions.

5 DISCUSSION

In this section, we further discuss the findings and key contributions of this work. We then identify the design implications, suggesting areas for further study and potential designs that could arise from our work.

5.1 The potential of AI for inter-generational communication in VR

Previous research has underscored the potential of AI to moderate inter-generational communication in non-immersive environments [35, 36, 91]. This work extends prior works by exploring how AI could be designed to support inter-generational communication in immersive environments. Our work shows that participants appreciated the real-time intervention of AI and content-aware

VR environments in facilitating inter-generational communication. Specifically, our study identified three key ways in which inter-generational users wish to leverage AI in VR.

First, participants recognized the potential of AI to *enhance mutual understanding* by bridging knowledge gaps between generations. Prior research highlights a widespread desire to maintain familial connections and share life experiences with family members [58, 59, 79]. However, the diverse cultural backgrounds, characterized by unique values, beliefs, and communication styles, often lead to misunderstandings between generations [58, 79]. Our findings suggest that AI could facilitate mutual understanding by effectively sharing ideas through *content generation*, and providing clear explanations of era-specific concepts through *search function*. When integrated with VR environments, AI has the potential to provide users with a richer array of visual assistance compared to non-immersive tools. Such integration could not only address the knowledge gaps but also enrich the life-sharing and storytelling experience, making it more vivid and tangible.

Second, AI was seen as pivotal in *enhancing conversation fluency* of two generations in VR through real-time interventions. Typically, the non-fluent conversations between two generations could result in brief and unsatisfying interactions, limiting opportunities for meaningful knowledge and cultural exchange [49, 85]. Our research demonstrates the effectiveness of AI's intervention in addressing these challenges. First, AI could propose relevant topics and activities aligned with mutual interests to prevent awkward silences and ensure continuous engagement. Second, it enables users to revisit and track previous discussions, fostering a more coherent dialogue and helping to reduce older adults' frustration associated with the feeling of 'being old' [67, 74]. Last, AI could identify potential conflicts and offer impartial, unbiased solutions to sustain positive communication experiences.

Third, participants suggested that AI could *promote active participation* between generations in VR. Prior research suggests that knowledge gaps and the tendency of younger generations to over-accommodate can hinder active engagement across generations, leading to miscommunication, a lack of genuine connection, and a sense of impatience among the youth [26, 62, 87]. To promote active engagement, they highlighted the importance of maintaining a balanced conversation, allowing each generation to share their viewpoints and emotions [26, 87]. Our participants noted that AI's neutral and respectful reminders effectively encouraged more talkative individuals to consider the feelings of others, avoiding disrespect. Additionally, AI's ability to understand the content and emotional tone of conversations allowed it to modify the VR environment in real time, enhancing the interaction's engagement. This adaptable VR environment encouraged users to share and listen more attentively to each other, thus enriching the quality of the interaction overall.

5.2 Design Implications of AI to better support inter-generational communication in VR

Based on our findings, we outlined key design implications and considerations aimed at guiding future researchers and developers in creating AI-based VR platforms that enhance inter-generational communication. Our implications focus on three primary aspects: 1) designing AI features that more accurately interpret users' intentions in this context; 2) developing AI capable of appropriate intervention and assistance in user conversations; and 3) deriving strategies for better integrating AI into VR environments to facilitate communication across generations.

5.2.1 Enhancing AI's interpretation of user intentions in inter-generational context. Unlike formal communication, inter-generational communication within families is often more casual and centered around personal topics, a relaxed tone, and language reflecting familial backgrounds [29, 49]. However, participants in our study reported difficulties with AI comprehending this informal style, especially when dialects, regional languages, or family-specific references were used. This made participants shift towards more standard speech, which led to discomfort and a lower willingness to engage with AI. Reflecting on participant feedback and existing research, we propose three strategies for enhancing AI's capability to interpret user intentions and maintaining a casual atmosphere in inter-generational communication.

First, we suggest that AI should understand users' life backgrounds, such as their age, living areas, educational backgrounds, and occupations. This would enable AI to understand the context and nuances of users' speech more accurately, thereby facilitating personalized responses that resonate with each user's unique experiences and viewpoints. This approach involves users providing basic information at the outset (e.g., age, occupation), while the AI refines its understanding through continued interaction, gaining insights into family members' personalities, communication styles, and family-specific references. Such a strategy balances immediate context-awareness with progressive learning, also addressing privacy concerns by allowing user discretion in information sharing.

Second, the integration of users' non-verbal cues, such as finger-pointing and gaze direction, is essential for AI systems to understand user intentions more precisely. As mentioned in Section 4.2, participants often interacted with the AI using non-verbal communication, similar to how they would interact with real persons. This underlines the importance of incorporating technologies like gesture recognition and eye-tracking in VR [52, 77, 82]. Such integrations would enable AI to interpret physical gestures and eye movements, allowing for a more comprehensive understanding of context and queries, extending beyond just verbal commands. This holistic approach is crucial for AI to respond accurately and in a manner that aligns with natural human communication styles.

Finally, participants emphasized the importance of AI recognizing dialects to enable natural, casual inter-generational communication. Many participants preferred using dialects with family but switched to standard Mandarin for AI comprehension, which was distracting. Recognizing dialects' role in intimate relationships and emotional connections, AI needs to adapt to these linguistic variations.

By leveraging these diverse inputs, AI can more effectively understand users' requirements and generate outputs that align more closely with their expectations and needs.

5.2.2 Designing appropriate AI's intervention in inter-generational conversations. Recent studies have demonstrated the efficacy of AI in facilitating human communication across various scenarios, including group meetings and social activities [3, 7, 92]. However, it remained unknown whether these findings were directly applicable to inter-generational contexts, which involved their own set of complexities such as navigating differing values and understanding generational hierarchies [26, 58, 79, 87]. Our research contributes to this field by showcasing the effectiveness of real-time AI intervention in inter-generational settings. Despite these positive outcomes, participants voiced concerns about the appropriateness of AI interventions, emphasizing the need for precise timing and approach to maintain harmonious and respectful conversations. This aspect is especially important in inter-generational communications, where communication dynamics are often more nuanced and sensitive [26, 38, 54, 87]. To enhance the appropriateness of AI interventions in inter-generational contexts, we propose two approaches based on our results.

First, we advocate for future research to focus on designing AI with a sense of boundary awareness. This means AI should be able to recognize and respect personal, cultural, and contextual boundaries of interactions that are unique to each family [92]. For instance, while some families might welcome AI assistance in resolving conflicts, others may prefer to engage in spirited debates without external intervention. To cultivate this nuanced comprehension, AI could be trained on diverse datasets that cover a wide range of scenarios and communication styles [92]. Additionally, incorporating training in ethical and cultural sensitivity, along with mechanisms for user feedback, can assist AI in navigating complex interactions more effectively [71]. For ongoing effectiveness and respectfulness, AI should continuously learn and update its knowledge and algorithms to stay in sync with new information and evolving social norms [6]. This comprehensive approach enables AI to effectively manage the subtleties of inter-generational communication.

Second, customizing AI intervention approaches to specific situations could improve users' acceptability. For instance, participants suggested visible prompts and private prompts for different situations as shown in Figure 3(b1,b2). Additionally, adapting the AI's appearance and personality to different scenarios was recommended, such as taking the role of a tour guide on family excursions or assuming the form of a friendly pet at family gatherings. This aligns with HCI research on multi-agents, emphasizing personalized interaction and adaptability in social contexts [13, 34].

Overall, it is vital for future research to integrate features in AI that understand and respect the dynamics and sensitivities of inter-generational interactions. Researchers should further explore more practical approaches enabling AI to discern and dictate acceptable behavior, thereby helping to regulate and enhance inter-generational communication.

5.2.3 Exploring various VR designs for optimal display of AI output to support inter-generational communication. In this work, we used VR to explore how participants leveraged AI to support inter-generational communication. We selected VR as our platform for two main reasons: 1) VR has shown promising outcomes in facilitating inter-generational communication by offering a sense of co-presence and relaxed communication atmosphere [2, 85], and 2) VR offers a variety of features — including virtual spaces, 3D objects, and spatial audio — which enable AI to showcase its capabilities, thereby eliciting innovative responses from participants [51]. Our findings indicate that integrating AI with VR opens new avenues for enhancing communication between generations. In these intelligent virtual environments, inter-generational pairs created images and 3D objects for clearer expression, generated VR scenes to boost engagement, and modified behaviors with the help of voice assistance. This approach provides a promising direction for future studies that aim to use VR in supporting inter-generational communication [2, 30, 85]. We recommend that future research explore more practical and innovative ways to integrate AI into VR environments, building on the potential shown in this study for improving inter-generational communication.

Based on participant feedback and suggestions, we identify two promising directions for integrating AI into VR to enhance inter-generational communication. First, participants proposed that AI could adapt avatars' appearances in response to conversational contexts, thereby creating more engaging interactions. Avatars, as digital representations of users in VR, significantly influence users' self-image and self-perceptions [41, 43, 55]. Such adaptive changes could offer immersive communication experiences and enhance empathy across generations. For example, in scenarios where AI detects that younger users struggle to understand the experiences of older generations during conversations, it could modify the avatars of these younger users (e.g., making the avatar appear older in appearance, slowing down the avatar's movements). This simulated aging process could potentially enable younger users to experience the sense of aging, thereby fostering empathy and a deeper understanding of the perspectives of the elderly [9, 73].

Second, we suggest that future research should explore the use of various VR visual effects to enrich social interactions. Prior studies have demonstrated the effectiveness of diverse visual representations — such as emotes, particles, creatures, fur, skeuomorphic objects, ambient light, and halos — in conveying users' social behaviors and emotional states in VR [8, 20, 44, 68]. Applying these effects in inter-generational communication could make interactions more engaging and appealing, potentially leading to more positive emotional states and a greater willingness to communicate [57, 66, 86]. These novel approaches offer exciting possibilities for future research in enhancing inter-generational communication through the integration of AI in VR environments.

6 LIMITATIONS AND FUTURE WORK

We acknowledge three limitations that motivate potential future research directions:

First, our study was conducted with inter-generational pairs from Chinese communities, which might introduce cultural and regional biases to our results [89, 90]. For instance, the optimal ways for AI intervention in inter-generational conversations might vary across different countries. While our findings highlight general AI perceptions and implications in this context, but further research with a diverse international sample is crucial to understanding the varying impacts of cultural differences on these perceptions.

Second, this work mainly focused on understanding users' perceptions and needs of AI in enhancing inter-generational communication. We did not conduct comparative evaluations to gauge AI's effectiveness against a standard task completion baseline. Building on our findings, future research should explore the impact of AI-powered VR applications more thoroughly. This could involve using control groups in subsequent studies for a clearer understanding of how AI interventions specifically aid inter-generational communication.

Moreover, although our AI probe-based co-design workshop revealed interesting insights, it lasted for a relatively short period and was conducted in a controlled laboratory setting. These factors may compromise the authenticity and practical applicability of the experimental outcomes [56]. Future research should focus on longer, more extensive, and ecologically valid studies outside the lab to better understand AI's long-term effects and gather practical insights for daily use in inter-generational communication.

7 CONCLUSION

Inter-generational communication involves the exchange of experiences and perspectives between different generations within a family, playing a vital role in emotional growth, self-esteem, and family bonds [37, 78, 88]. Our study explores the significant role of AI in enhancing inter-generational communication within VR environments, including enhancing mutual understanding, improving conversational fluency, and encouraging active participation, highlighting its role in bridging generational gaps in VR interactions. Our participatory design approach with inter-generational pairs also reveals users' perceptions and envisions of designing better AI features to support their communication. This research paves the way for future developments in communication tools, emphasizing the importance of AI which is not only technologically advanced but also sensitive to the complexities of human emotions and family dynamics, offering new opportunities for strengthening familial ties and improving the well-being of all generations.

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