

Designing Memory for Social Robots: Facilitating Conversations in Elderly Care during an Art Activity using Large Language Models

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by

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Abstract

This research explores the integration of episodic memory and visual short-term memory in social robots to enhance engagement and interaction with older adults, particularly those with dementia, through art activities such as painting. Dementia significantly impacts millions globally, being one of the leading causes of death worldwide. Furthermore, it creates a substantial burden on caregivers and healthcare systems. This research aims to leverage social robots to provide meaningful engagement, companionship, and emotional support to individuals with dementia.

The study involved developing a painting application using Android Studio and a conversational agent using generative AI. The AI model was enhanced with episodic memory and visual short-term memory, enabling it to reference past interactions through episodic memory and analyze painting progress through recent visual inputs with short-term memory. This qualitative study included 8 participants, and post-session interviews were conducted to gain deeper insights into the participants' experiences with the system.

The study suggests that memory-enhanced social robots can improve engagement and interaction quality among older adults interested in painting, but have limited impact on those uninterested in the activity. Mixed responses were observed regarding the robot's role as a companion, with some participants feeling a sense of company while others did not. Overall, participants did not experience frustration due to the robot's presence.

Challenges include response time and real-time awareness, highlighting the need for a more intelligent system. Given the small sample size of eight participants, future research should involve larger groups for more comprehensive and reliable data.

Keywords: Social robot, paint, generative AI, episodic memory, short-term memory, qualitative study, semi-structured interviews, engagement

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Contents

Abstract	ii
Acknowledgements	iv
List of Abbreviations	xiii
1 Introduction	1
1.1 Stages of Dementia	1
1.2 Challenges	1
1.3 Social robots with People with Dementia (PwD)	2
1.4 Need of memory in Social Robots	2
1.5 Use of Art Therapy in treating dementia	3
1.6 Elderly care	3
1.7 Research goal	4
1.7.1 Research questions	4
2 Background	5
2.1 Art therapy in Dementia	5
2.2 Technology with Elderly people	5
2.3 Studying engagement in PwD	6
2.3.1 Use of Robotic Pets in engaging PwD	6
2.3.2 Use of Humanoids in engaging PwD	6
2.3.3 Conversational engagement	7
2.4 Modelling memory of a social robot	7
2.4.1 Forgetfulness	9
2.4.2 Memory Retrieval	9
2.5 Use of Large Language models in social robots	10
2.5.1 Memory summarization using LLM	11
2.6 Large Language Models	11
3 Research Methodology	12
3.1 Guidelines for Communicating with PwD	12
3.2 Participants	12
3.3 Study Design: Adopting a Qualitative Approach	13
3.4 Overview of Activity	13
3.4.1 Wizard of Oz	14
3.5 Studying Engagement	14
3.5.1 Conversational engagement	14
3.5.2 Task engagement	14
3.6 Research Design	14
3.7 Experimental Design	16
3.7.1 Pilot study	16
3.8 Evaluation strategy	17
3.9 Design of Semi-structured Interview	18
3.9.1 Step 1: Reason for incorporating semi structured interview	18
3.9.2 Step 2: Participant recruitment	19
3.9.3 Step 3: Developing the semi-structured interview	19
3.9.4 Step 4: Conducting interview	20
3.9.5 Step 5: Analysis of interview	21
3.10 Data analysis	22

4	Technology and Implementation	24
4.1	Choice of robot	24
4.2	Comprehensive System Overview	25
4.2.1	Painting activity	25
4.2.2	Conversation Process	26
4.2.3	Design of Conversation	28
4.2.4	Conversation flow	28
4.3	System Architecture	29
4.3.1	Input-output	29
4.3.2	Natural Language Understanding Module	30
4.3.3	Memory Encoding: Episodic memory	31
4.3.4	Memory Encoding: Short-term memory	32
4.3.5	Memory Retrieval Module	32
4.3.6	Response generation	34
4.3.7	Choice of Large Language Models (LLM) in response generation	36
4.4	Painting application: PaintBuddy	37
4.4.1	App specifications:	37
4.4.2	App architecture:	37
4.5	Personalization of conversation	41
4.6	Fail-safe Methods	42
5	Results	43
5.1	Research Question1 (RQ1) result	43
5.1.1	Analysis of "Engagement in conversation"	43
5.1.2	Analysis of "Sense of companionship"	45
5.1.3	Analysis of "Valence of emotional state"	46
5.2	Research Question2 (RQ2) result	48
5.2.1	Analysis of interview responses	48
5.2.2	Analysis of paintings	50
5.2.3	Final summary on RQ2	51
5.3	Results on Memory of the robot	52
5.3.1	Episodic memory	52
5.3.2	Short term memory	54
5.4	Assessment of Dialogue Adherence to Guidelines for Conversations with PwD	56
5.4.1	Clarification	56
5.4.2	Exploration	57
5.4.3	Moderation	57
5.4.4	Providing clear and simple message	58
5.4.5	Validation	58
5.4.6	Rescue	58
5.4.7	Showing love and support	59
5.5	Use of tablet for painting	59
5.6	Overall motivation	59
6	Discussion	61
6.1	Significance of the Research	61
6.1.1	Potential use with PwD	61
6.1.2	Key findings	61
6.2	Answering Research Questions	62
6.2.1	Restating RQ1	62
6.2.2	Restating RQ2	63
6.3	Challenges	63
6.3.1	Challenges with the Robot	63
6.3.2	Challenges during the experiment	64
6.3.3	Research Limitations	64
6.4	Future work	64
7	Conclusion	66

A Appendix	68
B Appendix	73
C Consent Form	79
References	80

List of Figures

3.1	Experiment setup	16
3.2	Experimental design	23
4.1	Navel robot	25
4.2	A typical example of paint by numbers	26
4.3	System architecture	29
4.4	Input/Output setup	30
4.5	Entry screen of paint application	38
4.6	Image selection screen of paint application	39
4.7	Digital canvas of paint application: The Starry Night	40
5.1	Sense of perceived valence of emotion by category	48
B.1	Painting of participant from category 1	74
B.2	Painting of participant from category 2	74
B.3	Painting of participant from category 3	75
B.4	Conversation flowchart: initial scripted conversation	76
B.5	Conversation flowchart: General conversation	77
B.6	Conversation flowchart: General conversation and Ending	78

List of Tables

3.1	Analysis of RQ1 for evaluation	18
3.2	Metrics and their method of analysis	18
3.3	RQ1 probing questions	19
3.4	RQ2 probing questions	20
3.5	Main and probing questions for Robot's memory assessment	21
5.1	Session time for participants	60
A.1	RQ1 reasoning for main and probing questions	68
A.2	RQ2 reasoning for main and probing questions	69
A.3	Robot's memory: reasoning for main and probing questions	70
A.4	Robot's episodic memory: some examples	71
A.5	Robot's short term memory: some examples	72

List of Abbreviations

ADL Activities of daily living. 1

C1 Category 1: Participants who like to paint. 43, 45–48, 50, 51, 53, 59–61, 63, 66

C2 Category 2: Participants who don't like to paint but are open to trying it. 43–47, 49–51, 53, 60, 61, 63, 66

C3 Category 3: Participants who dislike painting and are not open to trying it. 43, 45–47, 50–55, 60, 63, 66

LLM Large Language Models. vii, 12, 13, 24, 27, 28, 33–36, 41, 64, 65

NLU Natural Language Understanding. 30

P1 Participant1. 43, 44, 60

P2 Participant2. 43–45, 60

P3 Participant3. 43, 44, 60

P4 Participant4. 43, 44, 60

P5 Participant5. 43, 44, 60

P6 Participant6. 43, 44, 60

P7 Participant7. 43, 60

P8 Participant8. 43, 45, 55, 60

PwD People with Dementia. vi, vii, 2–6, 12, 14, 15, 24, 25, 28, 33–36, 47, 49, 56–58, 61, 62, 64, 65

RQ1 Research Question1. vii, xi, 7, 14, 17–19, 43–47, 62

RQ2 Research Question2. vii, xi, 14, 15, 17–20, 48–51, 63

1

Introduction

Dementia has emerged as a significant contributor to disability and reliance on caregivers, placing considerable strain on both caregivers and the family of a person with dementia, as well as society at large. Dementia, currently ranked as the seventh leading cause of death, stands out as a major contributor to disability and dependence among the elderly on a global scale [92]. According to the latest 2023 report from the World Health Organization (WHO), there are currently more than 55 million people worldwide suffering from dementia [92]. Moreover, there are approximately 10 million new cases reported annually.

In 2019, the economic impact of dementia reached 1.3 trillion US dollars globally, with about half of these costs attributed to the informal care provided by caregivers such as family members and close friends [92]. On average, these informal caregivers dedicate approximately 5 hours per day to providing care and supervision [92]. In the United States alone, around 5.4 million people are affected by dementia, contributing to the significant healthcare burden [69]. The global incidence of dementia is projected to increase to 66 million by 2030 and exceed 115 million by 2050, indicating a substantial rise [69].

1.1. Stages of Dementia

The three stages of dementia are: Mild (or early), Moderate (or middle) and Severe (or late). Giebel et al. assessed the impact of dementia on Activities of daily living (ADL) varies across different stages of dementia: [31]

- **Mild Stage:** Individuals may experience minor memory lapses, such as forgetting words or where things are. However, they generally maintain independence in ADL, although more complex tasks might require some assistance.
- **Moderate Stage:** Memory issues become more pronounced. Individuals may struggle with planning or organizing, and need assistance with some ADL, like managing finances or shopping.
- **Severe Stage:** In this stage, individuals often require substantial assistance or full care. They may struggle significantly with communication and may not recognize familiar people. ADL such as eating, dressing, and personal hygiene typically require assistance.

Therefore Giebel et al. concluded that as dementia progresses, the ability to independently perform ADLs decreases, necessitating increased levels of care and support.[31]

1.2. Challenges

In the US, between 1982 and 1999, there was a decrease in the number of older people with chronic disabilities [59]. However, the total number of years that people with disabilities will need care is expected

to rise significantly [59]. It's estimated that 20% to 50% of the elderly will need basic nursing or help with daily activities [59]. The workforce available to provide care to the elderly is predicted to decrease by 40% from 2010 to 2030, highlighting a growing care gap [59]. The existing shortage of caregivers and limited geriatric medical training, along with a decreasing workforce, an aging population, financial issues, and rising consumer expectations, have led to significant staff shortages in healthcare facilities [29].

Chiao et al. suggest that sharing caregiving tasks in a practical way can help alleviate the stress experienced by caregivers [20]. Researchers propose interventions involving reminiscence activities [24]. However, facilitating reminiscence opportunities for PwD, along with communication, requires human resources. Consequently, some researchers are exploring computer-assisted interventions [98]. Therefore, this research can benefit both PwD and caregivers by using social robots. These robots can interact with PwD, reducing the caregivers' workload and providing them with more time to rest.

1.3. Social robots with PwD

Social robots have shown significant potential in assisting PwD by providing various forms of support that improve their quality of life. These robots, such as PARO, Pepper, and NAO, have been used to enhance social engagement, offer companionship, and provide therapeutic benefits [30]. Studies have demonstrated that these robots can reduce symptoms like agitation [41], anxiety [47], and depression [41, 80], while also improving mood [87, 88] and cognitive attention [83]. In therapeutic settings, social robots are employed to interact with PwD under the supervision of caregivers or therapists, thereby complementing human care rather than replacing it [8]. These robots are designed to understand and respond to the emotional states of PwD using facial expressions, verbal interactions, and other affective cues to foster a supportive and engaging environment [30].

One notable example is PARO, a therapeutic seal-like robot that elicits positive emotional responses and improves social engagement among PwD [62]. In a case study, an 82-year-old man named Thomas, who had not spoken in two years, interacted with PARO and displayed significant emotional reactions, including smiling and speaking. This interaction not only brought joy to Thomas but also altered the care staff's perception, emphasizing the importance of maintaining communication with PwD [62]. Similarly, the Giraff telepresence robot facilitates virtual visits between PwD and their families, helping to reduce agitation and improve mood [62].

Social robots can also help connect patients with their family members through video calls and other communication tools, thus reducing feelings of loneliness and isolation [75]. Overall, the integration of social robots into dementia care has been shown to alleviate caregiver burden, enhance patient well-being, and improve social interactions. By understanding and responding to the emotional and social needs of PwD, these robots play a crucial role in providing holistic care that addresses both mental and emotional health [30].

1.4. Need of memory in Social Robots

One major aspect of conversing with PwD is clarifying what the person said by repeating, asking questions, or restating as needed. Consequently, a robot with memory is necessary to fulfill this requirement. A memory allows the robot to remember previous statements and conversations, enabling it to repeat, restate, or ask follow-up questions accurately. This helps ensure that the PwD's communication is understood correctly.

Another important aspect of communicating with PwD is exploration, which involves seeking information from the person to understand their views and personal experiences. Therefore, if a robot can remember specific details about a person's experiences, opinions, and preferences, it can ask more meaningful and personalized questions. This makes interactions deeper and more engaging. Moreover, validating the person's expressions and emotions is also important. Remembering past interactions and emotional responses allows the robot to acknowledge and respond appropriately to the PwD's expressed or implied emotions. This builds trust and shows empathy. Therefore, a robot with memory is needed.

1.5. Use of Art Therapy in treating dementia

The American Art Therapy Association (AATA) describes art therapy as a psychological health field [6]. In this practice, people are guided by an art therapist to use various art forms and creativity to create their own painting [6]. This methodology is employed across a diverse range of applications. It is designed to facilitate people to examine their emotions, resolve emotional issues, enhance self-understanding, control behavior and addictions, build social abilities, better grasp reality, lessen anxiety, and boost self-confidence [6]. Dementia comes in various forms, among which Alzheimer's disease is the most prevalent [68]. Because Alzheimer's can last a long time from when it's first found until the end, treatments that help with mood and behavior problems, make life better, and help caregivers feel less stressed are important. Visual arts offer a supportive approach for PwD by leveraging their existing abilities and strengths, focusing on what they can still do [57]. It enables them to engage in art appreciation and creation, tapping into their still-intact visual and emotional processing capabilities. Despite cognitive challenges, those with dementia retain procedural learning and memory, aiding them in art production [57]. Thus, visual arts become a medium through which they can process basic concepts and convey emotions. [16].

Dementia often falls under a medical approach focused on deficits, with societal views largely shaped by fears of loss. However, incorporating art-based activities into dementia care can significantly improve the well-being and quality of life for PwD [94]. Windle et al. conducted a 12-week visual arts program, demonstrating that art activities led to better attention, happiness, self-worth, and reduced sadness. This positive impact suggests that dementia care professionals and cultural organizations should integrate art-based activities as a standard part of care [94]. Similarly, Wang et al. found that art therapy supports the mental, social, and emotional well-being of PwD, enhancing focus, communication, and emotional expression, which in turn benefits both patients and caregivers by improving mood and behavior [91].

Additionally, Rusted et al. reported that over a 40-week period, participants engaging in art therapy showed significant improvements in mental acuity, physical involvement, calmness, and sociability compared to a control group [78]. These benefits persisted beyond the therapy sessions, although there was an increase in depression scores after the sessions ended, indicating strong engagement with the therapy [78].

Therefore, by focusing on what PwD can create and express, rather than on their deficits, art therapy fosters a more positive approach to dementia care, benefiting both patients and caregivers [32, 42]. Recognizing these benefits, there is a growing interest in how technology can further support and enhance the well-being of PwD.

1.6. Elderly care

Dementia is often accompanied by memory-related issues, which can significantly impact daily life for those affected. These challenges are common not only in dementia but also as part of the normal aging process, although they are more pronounced in dementia. In old age, there are deteriorations in the processing, learning, and recovery of new information, problem-solving, and speed of response [58]. One of the most frequent problems in aging is the decline of memory. In fact, the subjective complaint of lack of memory appears in 70% of elderly subjects [58]. Addressing these challenges is crucial to ensure proper care for the aging population and to support the health and sustainability of caregivers as well.

Just like in dementia care, there are also fewer caregivers available for elderly care as well [29]. This growing care gap puts more pressure on healthcare systems because the need for elderly care services is rising faster than the number of qualified caregivers [29]. Both professional and informal caregivers face increased workloads and stress due to the lack of enough workers. The physical, emotional, and financial strain on caregivers is likely to get worse, affecting their well-being and ability to provide good care [29]. Therefore, we shift our focus from individuals with dementia to older adults for the scope of this research.

1.7. Research goal

As the global population ages, the prevalence of dementia is rising, presenting a compelling case for leveraging technology to offer support and enrichment to those affected. Engaging in artistic activities has been shown to yield positive outcomes in PwD, enhancing their quality of life. In this context, my research aspires to refine and enhance the interactions between PwD and a social robot during collaborative activities, such as art-making.

My research aims to facilitate supportive conversations for PwD and elderly individuals, ensuring these interactions are sensitive and do not cause discomfort. Additionally, it seeks to develop a framework that fosters companionship, meaningful engagement, and interaction. I am dedicated to exploring innovative approaches to ensure these conversations are effective, considering the emotional and cognitive states of PwD and elderly individuals. The goal is to create an interactive environment where they can actively participate in creative activities and engage in enriching, supportive dialogues. This harmonious blend of art and conversation aims to nurture their well-being, offering a touch of joy in their journey. The aim is to enhance the quality of interaction, providing comfort and ease to those in vulnerable states through empathetic and intuitive communication strategies.

1.7.1. Research questions

1. How does incorporating episodic memory and visual short-term memory in a social robot affect the following aspects during interactions with older adults?
 - Engagement in conversation
 - Sense of companionship
 - Valence of emotional state
2. How does introducing an art activity program facilitated by a social robot affect the engagement levels of older adults in the activity?

2

Background

2.1. Art therapy in Dementia

Wang et al. state that painting in art therapy for dementia care is beneficial because it provides a non-verbal medium for expression and communication. This can be particularly useful for PwD who may struggle with verbal communication [91]. They further mention that engaging in painting allows individuals to express emotions and thoughts that might be difficult to articulate otherwise. This form of creative expression can improve mood and self-esteem, reduce stress and anxiety, and offer a sense of accomplishment and personal satisfaction.

Lancioni et al. discovered that coloring, a form of creative therapy, promotes positive behaviors and sometimes appeals more than music, highlighting the broad applicability of creative therapies in dementia care [46]. Stewart et al. also emphasized that painting provides essential visual and tactile stimulation, helping to maintain cognitive processes, reduce agitation, and enhance social interaction and sensory stimulation, thereby maintaining a sense of self and dignity for those with dementia [82]. Painting can also stimulate cognitive functions and memory recall, contributing to an overall enhancement of the quality of life for PwD.

2.2. Technology with Elderly people

Memory problems, a common issue with aging, significantly impact the daily lives of individuals. Researchers have been advocating for the use of reminiscence activities as interventions [24]. However, these activities, which require interactive communication, often demand substantial human resources. Consequently, there is a growing interest among some researchers in exploring computer-assisted interventions to facilitate reminiscence activities for PwD. These technological solutions aim to provide effective support with less reliance on human resources [98]. Yoshi et al. designed a system to stimulate memory recall through the use of old photographs and an assistant agent. This method is designed to evoke past memories and experiences, particularly those related to childhood environments, architectural elements, and personal narratives that may have been forgotten. The goal is to reconnect individuals with their past by bringing these dormant memories to the forefront [99]. Similarly, Curry et al. developed a conversational agent named Betty, designed for reminiscence therapy [25]. Their research indicates that using Betty for reminiscing can effectively improve age-related memory loss and enhance the subjective well-being of users. This suggests the potential of conversational agents as effective tools in supporting cognitive health and emotional well-being in aging populations.

The integration of AI and robotics aims to enhance cognitive abilities and improve the quality of life for the elderly with cognitive impairments [33]. Gochoo et al. state that AI technologies can be utilized to create personalized training programs that adapt to the individual's cognitive level and progress. In this research, robotic pets and assistants were used to engage the elderly in interactive activities that stimulate cognitive functions. These technologies help in memory training, problem-solving exercises, and other cognitive tasks, providing a supportive and engaging environment for cognitive rehabilitation and maintenance, especially beneficial for PwD. Beun et al. investigated the impact of Embodied

Conversational Agents (ECAs) on memory retention and the extent to which users attribute human characteristics to these agents [9]. The study found that people interacting with a realistic-looking Embodied Conversational Agent (ECA) had better memory performance than those without any ECA.

A study by Liao et al. sheds light on the views of non-healthcare workers, care partners, and healthcare workers regarding the use of the humanoid robot Pepper in dementia care [52]. They have shown a positive stance towards implementing Pepper, recognizing its innovative qualities and potential benefits in enhancing caregiving practices. Huang et al. designed a conversational agent that proactively starts and sustains dialogues, adjusts its responses based on user interaction, and helps users remember their daily activities [35]. This creates a nurturing and supportive communication setting for people with memory difficulties. The goal is to improve cognitive activity and social interaction, particularly benefiting those in the initial stages of dementia or with minor memory challenges.

2.3. Studying engagement in PwD

A study by Jiska et al. introduced a theoretical framework for understanding engagement in persons with dementia. The framework, called the "Comprehensive Process Model of Engagement" [21], highlights the influence of environmental, person, and stimulus attributes on engagement. Key activities included music therapy, pet therapy, structured activities, and simulated family videos. Jones et al. assessed engagement across six dimensions: emotional, verbal, visual, behavioral, collective, and signs of agitation [39]. The study highlighted the use of social robots, such as telepresence and companion robots, to engage people with dementia. These robots helped to reduce behavioral and psychological symptoms of dementia (BPSD) and promoted social inclusion and emotional connection.

2.3.1. Use of Robotic Pets in engaging PwD

The "Engagement of a person with dementia scale" [40] was developed to assess behavioral and emotional engagement in PwD. It measures five areas of engagement: affect, visual, behavioral, social, and verbal. The scale was validated through the Delphi technique and showed strong psychometric properties. Activities assessed included psychosocial interventions like interaction with PARO, the therapeutic robotic seal, and other social and recreational activities.

Similarly, many robotic have been designed to provide companionship to PwD. The CuDDler robot [63], a prototype developed in Singapore, was used to explore its effects on engagement and emotional responses in PwD. CuDDler is a robotic teddy bear equipped with sensors and motors to detect and respond to touch. Participants interacted with CuDDler in 30-minute sessions, facilitated by a nurse, aiming to see the robot's potential to reduce agitation and provide companionship. Despite mixed responses, CuDDler was most effective for participants with higher agitation levels, offering a form of social interaction and comfort.

Another robotic pet, Pleo [74] was used to facilitate social connections for older adults with dementia. The robot allowed remote caregivers and family members to interact with the residents via video calls. This method aimed to reduce feelings of loneliness and improve the overall mood of the participants. The use of telepresence robots proved beneficial in maintaining social ties and providing emotional support, highlighting the potential of technology in enhancing the quality of life for PwD.

2.3.2. Use of Humanoids in engaging PwD

The Pepper robot was used in a study to play music for PwD, aiming to evoke memories and improve comfort levels. The results showed that listening to music played by Pepper helped participants recall past experiences and enhanced their comfort and happiness [26]. Similarly, the PALRO robot was utilized to encourage communication, activity expressions, intellectual activities, and fun among PwD [36]. By connecting to the internet to gather information such as news and weather, PALRO tailored activities to alleviate dementia symptoms. The study found PALRO more effective for people with mild dementia compared to those with severe dementia.

In another study, Kabochan, the humanoid social robot, interacted with PwD involving 103 participants. Kabochan engaged PwD through activities like talking, cuddling, and carrying, aiming to measure their engagement and ease of use [18]. Despite no significant changes in attitude toward

robot acceptance, Kabochan showed potential in gradually increasing ease of use for participants.

Building on these findings, Ryan, the companion robot, communicated with individuals through spoken dialogue, recognized emotions via facial expressions, and entertained them by playing favorite songs or movies, designing cognitive games, and telling stories with personalized pictures [1]. A pilot study with six patients showed improvements in their quality of life, mood, and cognitive level.

Moreover, the NAO robot was used in psychomotor therapy to assist with physical and breathing exercises, as well as to increase body awareness and verbal skills [77]. NAO engaged participants emotionally and improved their well-being and satisfaction through interactive sessions conducted alongside a therapist.

2.3.3. Conversational engagement

As per RQ1, one aspect focuses on studying the conversational engagement of the participant. This analysis is crucial to understanding how participants engage when interacting with the robot. Coker et al. mention conversational engagement as the extent to which participants maintain a smooth and seamless flow in their conversation [22]. The researchers indicate that high involvement in conversation is conveyed through improved interaction management and coordination, as demonstrated by: "more verbal fluency and composed vocalizations, fewer silences, fewer response latencies, more coordinated physical behavior, and more coordinated speech, than low conversational involvement." [22]

They also emphasize Altercentrism, which is the tendency to show interest in, attentiveness to, and adaptability to the other person in a conversation. Therefore, they further state that high conversational engagement can be demonstrated by more Altercentrism, which can be depicted as: "(a) more kinesic/proxemic attentiveness, involvement, interest, focus, and alertness and (b) more vocal warmth, interest, involvement, pleasantness, friendliness, and appeal than low conversational involvement." [22]

2.4. Modelling memory of a social robot

Tulving et al identified five distinct yet interconnected memory systems. These include procedural memory, responsible for skills, actions, and simple conditioning; Perceptual Representation System, involved in perceptual facilitation and object identification; short-term memory, encompassing working memory; semantic memory, managing general knowledge concerning the world; and episodic memory, enabling recall of personal experiences [86]. Binder et al. have demonstrated that memory relies on social cues in both the encoding and retrieval processes [10]. The three primary frameworks enabling the exploration of novel research questions related to Virtual Conversational Agents (VCAs) are "socially motivated information processing, transactive memory, and theories of a dynamic autobiographical memory system." [10].

Machine translation, retrieval-based response selection, sequence-to-sequence models, and reinforcement learning for policy selection (as demonstrated by Li et al. [50]), aim to enhance generic system responses. However, these methods demand extensive training data for optimal performance, posing challenges in availability and acquisition across diverse domains. Additionally, the creation of Embodied Conversational Agents (ECAs) goes beyond a mere conversational interface, as these agents are meant to exhibit lifelike and credible actions and reactions during prolonged interactions with humans [15]. Campos et al. [13] state that present episodic memory architectures for Embodied Conversational Agents (ECAs) are crafted to store and organize pertinent episodes gathered from previous interactions, with the aim of utilizing them in subsequent dialogs aligned with specific interaction goals.

Campos et al. explores various conversation approaches using the memory of past conversations, leveraging knowledge gained from prior interactions [13]. Their system design involves re-situated learning as the learning mechanisms. The learning mechanisms in the system are overseen by a dialog manager, which maintains all utterances in a graph database, inclusive of a comprehensive record of past conversations with each user. This setup enables the robot to navigate the graph and its conversation history when determining which utterance to express. The process of utterance selection involves evaluating the user input and current state against the agent's policy (π) for each time step (t). The agent chooses the utterance at time t that maximizes its goals, as defined by its policy. Similarly

Hsiao et al. [34] leveraged the autobiographical memory of the user, along with Natural Language Understanding (NLU) to develop a memory architecture for their agent. The NLU module retrieves significant memory items and performs sentiment analysis on user utterances. This information is then conveyed to the Dialogue Management (DM) module, which oversees data maintenance and directs other modules to initiate actions. The memory knowledge base stores new data items, and related concepts are retrieved, while the skills module utilizes data-driven and script-based methods for sentence generation. The DM determines the appropriate sentence based on context, and the Natural Language Generation (NLG) module facilitates the output of the robot's responses. O'Shea et al incorporated autobiographical memory to store users' past experiences, and WordNet [60] was utilized to establish a semantic knowledge base for general knowledge. Memories were activated when a word with semantic similarity matched against the database of general items [66].

Conway et al categorized autobiographical memory into three levels: "Lifetime Periods, General Events, and Event-Specific Knowledge" [23]. Campos et al. created MAY, a conversational virtual companion that accumulates user-shared memories within the aforementioned three-layer knowledge base to sustain prolonged interactions [14].

Knob et al. modeled the memory of their agent utilizing event specific knowledge and general events. And all the memories were stored in Short-term and Long-term memory. In addition, they recorded the general events by including timestamps, event ID, event type, as well as the emotion and polarity associated with each event. On the other hand, event-specific knowledge also featured activation and weight, causing logarithmic decay in short-term memory based on the activation value. The response's importance was determined by its weight [44]. Sanchez et al. assert that, for any interactive task, three fundamental actions are performed: "acquisition, storage/update, and retrieval of information." [79]. Sanchez et al. utilize an episodic long-term memory system to manage conversations, incorporating information on the session, individuals interacted with, manipulated objects, and performed behaviors. This includes details such as session ID, start and end dates and times, location, and the first person encountered. Information about interacted individuals comprises ID, name, facial image, age, city, and country of origin. Manipulated objects include ID, name, and image, while behaviors involve ID, name, associated session, and the person executing them.

Soar, a comprehensive cognitive architecture developed by Newell, has been employed for constructing extensive knowledge-intensive AI agents [64]. Nuxoll states that "Soar comprises short-term working memory and long-term procedural memory." [65]. Moreover, Soar's procedural memory contains if-then production rules. When the conditions of a production are met by working memory contents, the production fires and executes actions, such as adding or removing elements. All matching rules fire simultaneously [65]. They developed a system incorporating long-term procedural memory and episodic memory. At specified intervals, the module records new episodic memories, forming a retrievable storage for the agent.

Perez et al. introduced a cognitive-affective architecture based on Soar, incorporating an affective model inspired by ALMA. This architecture integrates short-term, medium-term, and long-term affective characteristics, encompassing emotions, mood, and personality, respectively [72]. Soar is an architectural framework created to simulate the intelligent behavior exhibited by an agent [45]. They categorized long-term memory into procedural, semantic, and episodic memory, each with specific components. The processing cycle involves five phases: Input captures new information and updates affective state components, Proposal suggests actions based on the system's state, Decision selects an action considering various sources, Application applies the chosen action, and Output sends information and orders to the environment based on the applied action. Similarly, Lim et al. segmented their memory architecture into working memory, sensory memory, and long-term memory to establish a conversational pattern for transitioning between conversation topics [53].

Kim et al state that "Dialog systems are examined through two perspectives: task-oriented dialog systems and small talk systems. Task-oriented dialog systems are employed to aid in specific tasks within defined domains." [43]. They designed a Personalized Dialog system by gathering user-related facts. The system extracts triples from user input sentences, identifying and storing user-related triples by matching with manually written triple patterns.

Xu et al. provided a dynamic working memory mechanism for capturing long-term semantic cues

within a conversation. This is achieved through ongoing semantic interactions between utterances, ensuring the context representation is continuously updated. Subsequently, the results from the dynamic working memory are utilized to offer valuable cues to the encoder-decoder architecture, enhancing its ability to generate responses in a given dialogue [97].

The episodic memory model in Elvir et al's architecture incorporates four fundamental components: "memory interfaces, a back-end database, contextualization processes, and various analysis services" [27]. Memory interfaces facilitate communication between episodic memory and Embodied Conversational Agents. A server-based back-end database stores episodes and manages conversational data. The contextualization process handles input, stores it, indexes episodes, and determines relevant retrieval. Analysis services extract information from the dialogue.

2.4.1. Forgetfulness

'Forget' denotes the loss of previously encoded and stored information in someone's long-term memory, which can occur spontaneously or gradually, making old memories challenging to recall [61]. Introducing forgetfulness in a robot aims to enhance user relatability, fostering the development of a robust, long-term companionship with the robot [11].

According to Ebbinghaus, memory retention diminishes over time but is replenished through periodic review [101]. Moreover, repeating and reviewing information over an extended period is more effective for solid memory retention than intensive short-term learning. Once knowledge is firmly established in memory, it is less likely to be forgotten, allowing us to distinguish between important and unimportant knowledge units by modeling the forgetting curve [101]. Kim et al. applied Ebbinghaus' forgetting curve, by assigning retention and strength to each knowledge unit in a Personal Knowledge Base (PKB). When a new knowledge unit is extracted from user input, it is received by the Personal Knowledge Manager (PKM). If not in the PKB, it is inserted with initial values. If it already exists, the PKM updates similar targets' retention and strength, determined by a weighted dice similarity function with a threshold. Retention and strength in the PKM are updated as needed through a process that includes forgetting and recharging steps [43]. They created a relevance score ($rel(s)$) to assess the suitability of a response (s), giving weight to responses containing user-related facts and frequently used general responses. It is calculated using statistical information from the example database, along with retentions of user-related triples and knowledge units. The design assumes that a general response has many similar counterparts in the example database.

Bui et al. designed a mechanism to enhance memory performance by removing out-of-date information [12]. It is based on a time decay-based approach, where the active level of each memory item is calculated using a function that considers emotional salience and the number of times that memory was retrieved in the past. This function determines the likelihood of each memory item being retrieved and, based on a threshold, decides whether the memory item should be kept or removed. This approach allows the robot to forget less relevant or outdated information, thereby improving the efficiency of its memory system.

2.4.2. Memory Retrieval

In recent times, there's been a growing focus on representing emotions in robots to improve sustained interactions with humans. Specifically, generating human-like emotions in robots during these interactions is crucial for establishing trust between humans and robots. To achieve this, there has been significant research into human emotions from a psychological perspective, aiming to accurately depict robot emotions that are socially acceptable [12]. For memory retrieval when a robot observes a scene containing an object, Bui et al. used a Sensory Representation to extract features of the new object [12]. These features are then compared with the corresponding features of previously seen objects to find the most similar object. The similarity between two objects is determined using the object's color histogram and Scale-Invariant Feature Transform (SIFT) features. Lu et al's system had an encoding policy that determined when the system stores memory snapshots. This design aims to simulate how the human neocortex interacts with hippocampal structures for memory encoding and retrieval. For retrieval, the model utilizes a "leaky competing accumulator process (LCA)". In this process, memories compete for retrieval based on how well they align with the current state of the neocortical network. The output of this competitive retrieval is then reintegrated into the neocortical network [56].

Lee et al. focused on a "hierarchical emotional episodic memory structure" [48]. This structure is designed to efficiently store and retrieve emotional experiences, as well as anticipate future experiences and their emotional consequences. A memory system here consists of multiple layers, including an input field, an event field, and an episode field. Memories are encoded with temporal information, distinguishing between emotional and non-emotional events. They performed memory retrieval in a multi-step process that starts by selecting a specific episode node. The weight vector associated with the chosen episode is read, and the index of the largest element in this vector is determined. This index is then placed into a sequence queue. The largest element in the weight vector is reduced by a pre-determined integer value, and the process of updating the sequence queue and reducing the weight vector is repeated until no elements greater than zero remain. The final sequence queue represents the sequence of event indexes, effectively reconstructing the sequence of events from the stored memory.

Part et al. designed an agent using generative AI which consists of a memory stream [71]. The memory stream in the agent's system is a detailed list of memory objects, each containing a natural language description, creation and recent access timestamps. An observation, a direct perception event, is the most basic memory element. Memory scoring is based on three criteria: Recency (favoring recently accessed memories), Importance (prioritizing memories deemed crucial by the agent), and Relevance (emphasizing memories pertinent to the current context, measured by cosine similarity of embedding vectors). The retrieval function combines these elements to score all memories. Similarly, Liang et al's Self-Controlled Memory (SCM) system has memory storage and retrieval through Large Language Models (LLMs) with long-term (archived) memory, short-term (flash) memory, and a memory controller [51]. The SCM system stores all historical information in the archived memory, while the flash memory captures real-time memory information. The memory controller activates relevant memories based on the current input, ranking each memory by relevance and recency. The system then combines these memories to provide coherent and context-aware responses, enabling the LLMs to handle ultra-long texts and maintain relevant information over extended interactions. The scoring mechanism for each memory in the system is determined by adding its recency and relevance scores together, forming the overall rank score. This rank score combines both how recently the memory was accessed and its pertinence to the current context.

2.5. Use of Large Language models in social robots

Autonomous agents based on LLM typically integrate principles and mechanisms drawn from cognitive science research on human memory processes [89]. Fischer et al. developed a conversational agent with internal states for both the speaker and listener [28]. In each round of conversation, these states act as prompts for LLM, serving as short-term memory for the agent. However, some memory models integrate both short-term and long-term memory. The Generative Agent by Park et al. utilizes a hybrid memory model to support the behaviors of agent. The short-term memory holds contextual information regarding the agent's present state, whereas the long-term memory contains the agent's previous behaviors and beliefs, retrievable based on present events [71]. Park et al's architecture comprises three main components. The first is a long-term memory module, the memory stream, recording the agent's experiences in natural language. A memory retrieval model prioritizes records based on relevance, importance, and recency to guide the agent's behavior every moment. The second component, reflection, synthesizes memories, aiding the agent in formulating conclusions about itself and others. Planning, in turn, transforms conclusions and the present environment into both detailed behaviors and high-level action plans. Subsequently, these reflections and plans are integrated back into the memory stream, shaping the agent's future behavior [71].

Yun et al proposed Large Language Models (LLMs) such as GPT-J 6B and BLOOM to be incorporated into a humanoid robot to make it to act as a debate partner [100]. The LLMs are used to process, understand, and respond to human speech, facilitating a debate-like interaction. However, this approach yielded unsuitable responses for debate reasoning. To improve this, an "OPINION STATEMENT + BECAUSE" format was employed, generating more relevant debate responses but still including some unrelated content. Consequently, a multi-stage post-processing and filtering system was implemented. This involved a validation check using Enchant for English language accuracy, filtering out subjective opinions, especially personal pronouns and certain phrases indicative of advertisements. The process also included a four-level iterative questioning system to refine the robot's responses for

more constructive and relevant debate contributions.

Liang et al. developed a Self-Controlled Memory System (SCM) with the ability to store long-term memories, enabling it to handle extended inputs and preserve information following multiple interactions with the user [51]. The agent follows a concise six-step process: input acquisition, memory activation, memory retrieval, memory reorganization, input fusion, and response generation, handling interactions by incorporating present observations and relevant memories. Li et al. emphasized the significance of aligning the working memory with the task-specific context when relevant [49]. In the absence of task-related context, the model should depend on world knowledge acquired during the pretraining phase.

2.5.1. Memory summarization using LLM

Memory summarization in the paper is a key component in Liang et al's system [51]. This process involves consolidating multiple memories into a single activated memory section. The system uses specialized prompts like "Below is a conversation between a user and an AI assistant. Please provide a summary of the user's question and the assistant's response in one sentence each, with separate paragraphs, while preserving key information as much as possible" [51], which are designed for memory summarization in individual interactions, such as dialogue tasks. These prompts enable the stacking of various memory contents into a cohesive summary, facilitating efficient handling of extensive dialogue or textual data. This method allows the model to maintain coherence and relevance over lengthy interactions, enhancing its capability for complex dialogue tasks. However, in Park et al's system, the memory summarization process involves an iterative summary paradigm enhanced with a feature for creating topic-specific summaries. When a user queries about a particular subject, the model delves into its previously summarized memories to extract pertinent information. This method allows for the generation of concise summaries that are directly relevant to the user's specific request, effectively utilizing the extensive memory data stored in the system [71].

In addition to this, Wang et al. proposed a summarization method by prompting large language models (LLMs) to generate recursive summaries. This process starts with the LLM producing a summary from a short dialogue context. The model then continuously updates and creates new summaries by incorporating previous memory and subsequent dialogue exchanges. This method allows the LLM to effectively maintain key information in long-term dialogue, enabling consistent and contextually relevant responses in extended conversations [90].

2.6. Large Language Models

Xia et al conducted training for a set of competitive Sheared-Llama models using significantly fewer computational resources compared to conventional pre-training methods. Their findings suggest a promising approach to generate compact Language Model Models (LLMs) at a reduced cost, especially when robust large-scale models are at disposal. However, because of limitations in computational resources, the experiments were exclusively carried out using a 7B parameter model [96].

Jiang et al state that Mistral 7B exhibits outstanding performance in code, mathematics, and reasoning assessments. When assessed in terms of reasoning, comprehension, and STEM reasoning, especially in MMLU (Mean Match Length for Understanding), Mistral 7B achieves a level of performance comparable to what one might anticipate from a Llama 2 model that is more than three times its size [38]. A higher version of Mistral was released as Mixtral 8*7B. Jiang et al. concluded that: "Mixtral was trained with a context size of 32k tokens and it outperforms or matches Llama 2 70B and GPT-3.5 across all evaluated benchmarks. In particular, Mixtral vastly outperforms Llama 2 70B on mathematics, code generation, and multilingual benchmarks. We also provide a model fine-tuned to follow instructions, Mixtral 8x7B - Instruct, that surpasses GPT-3.5 Turbo, Claude-2.1, Gemini Pro, and Llama 2 70B - chat model on human benchmarks." [37]

3

Research Methodology

3.1. Guidelines for Communicating with PwD

To build an agent that can handle discussions, like those with PwD, it's important to first learn the appropriate way to communicate in these situations. Understanding, effective communication methods is key. These skills not only improve the agent's design but also enrich the interaction, offering support and comfort.

Perry et al. developed a classification system for interactions with PwD, categorizing the various methods used in communication and engagement [73].

- **Clarification:** Ensuring comprehension of a PwD's communication by using repetition, restatement, or questions.
- **Exploration:** Seeking specific information about the person to understand their personal experiences, views, and preferences.
- **Moderation:** Facilitating general conversation by introducing topics, keeping the conversation flowing, and managing the direction of the discussion.
- **Validation:** Acknowledging and responding to the expressed or implied emotions of PwD, both verbally and non-verbally.
- **Rescue:** Providing context, suggestions, or assistance to make sense of isolated or unclear statements by PwD.
- **Use of Discourse Markers:** Employing socially appropriate strategies that align with expectations, like acknowledging comments and explaining actions.
- **Connection:** Building a personal rapport with PwD by sharing personal information and identifying common experiences.
- **Assistance:** Ensuring the PwD's physical comfort and their inclusion in group settings.

Moreover, the California Department of Social Services also provides guidelines for talking to PwD, focusing on strategies that promote positive interactions [81]. These include ensuring a welcoming atmosphere, grabbing their attention, delivering clear messages, asking simple questions, waiting patiently for answers, observing non-verbal cues, breaking down tasks, diverting attention during distress, showing love and support, and keeping a light-hearted attitude [81]. These methods aim to improve and make communication with those experiencing dementia more understanding and compassionate.

3.2. Participants

This study specifically aims to enhance engagement with PwD, focusing on those in early and middle stages of the condition. However, using advanced technologies like LLM recognizes the challenges and potential safety risks of involving PwD directly in the evaluation. Moreover, as mentioned in Section

1.6, elderly people also experience memory decline. Therefore, this system can be utilized for elderly people as well.

To mitigate risks, the evaluation strategy has been adapted to involve elderly people without dementia. Participants were recruited from in and around Delft, and throughout the evaluation, they were required to engage in conversation with the robot while simultaneously painting. They had the freedom to discuss various topics with the robot, with the extent of information shared is entirely up to the individual. This approach allows us to safely test the system in a controlled yet realistic setting, gathering valuable data on user interaction without directly exposing vulnerable populations to potential risks.

3.3. Study Design: Adopting a Qualitative Approach

Bearing the primary objective of this research in mind: to create a system tailored for elderly people that facilitates engagement in conversation while simultaneously ensuring their comfort when interacting with a robot, a qualitative study approach has been adopted. The evaluation process prioritizes the perspectives and voices of participants, providing insights into their thoughts, feelings, and experiences from their viewpoint. Moreover, qualitative research exhibits greater adaptability in managing the complexities and contradictions present in human behavior and social phenomena. It is capable of investigating the inconsistencies in participants' perspectives or actions concerning human-robot interaction, thereby providing a comprehensive insight into the subject of the study [84].

3.4. Overview of Activity

This system integrates a painting activity with a robot designed to engage elderly participants. Using Android Studio, a painting application has been developed on a tablet. This app features an easy user interface and provides three pre-drawn images of paintings by Vincent Van Gogh, varying in difficulty. Participant selects one to paint.

The robot enhances this experience by guiding the participant through the app and offering companionship while they paint. Initially, the robot explains on how to navigate through the painting application and how to use the painting tools provided on the tablet to paint. Once the participant is ready to paint, the robot initiates conversations with questions like "Which color would you like to use next?" or "What feelings does this image by Vincent van Gogh evoke for you?" These questions are meant to start discussions and help create memorable interactions. Further detail on response generation is provided in Section 4.3.6

Conversations are powered by LLM, and they're stored as episodic memories within the robot for later retrieval. The robot ranks these memories as discussed in Section 4.3.5, referring back to them during the painting session to deepen the conversation.

Screenshots are taken from the tablet at fixed intervals and transferred to the robot. These screenshots serve as the robot's visual short-term memory. Only the most recent two screenshots are saved in the robot's short-term memory; all previously received screenshots are deleted. By comparing these successive screenshots, the robot can evaluate the changes made by the participant between the intervals of the last two screenshots. This capability ensures that the robot's responses are relevant and informed, enhancing the quality of companionship it provides. This seamless integration of painting and conversation marks a significant improvement, allowing the robot to engage in meaningful dialogue based on live updates of the participant's painting activity. The robot uses this information to offer timely praise and encouragement, aiming to enrich the painting experience.

Additionally, participants have the flexibility to direct the conversation towards other personal interests or daily life, with the robot responding in real time, thanks to the LLM. However, the robot is guided to stay on painting-related topics. So, once the participant finishes discussing their topics, the robot switches back to painting-related discussions. This setup not only fosters a creative atmosphere but also nurtures an interactive and supportive relationship between the participant and the robot. In essence, this system not only helps participants engage in a creative activity but also fosters interaction through a smart, conversational companion. A more detailed description of the complete activity is described in Section 4.2.

3.4.1. Wizard of Oz

The activity is supposed to be performed in a way such that the participant speaks to the robot and the robot listens and replies. However, the speech recognition of the robot is not used, and the participant responses are typed manually to the robot via a conversational interface. Speech recognition was not used because it is still not 100% accurate. Even slight mistakes in speech recognition could create faulty memories for the robot, potentially causing issues in the entire experiment process and the results.

3.5. Studying Engagement

In this research, RQ1 focuses on conversational engagement, and RQ2 focuses on task engagement. Therefore, in this section we discuss how we studied engagement for both RQ1 and RQ2.

3.5.1. Conversational engagement

Therefore, we study conversational engagement by analyzing the interactions between the participant and the robot, evaluating it based on the concepts of Coker et al., which focus on maintaining seamless conversation and altercentrism [22], as previously discussed in Section 2.3.3. Our focus is specifically on the response latencies of the participants and coordinated speech to assess effective turn-taking. Participants with lower response latencies demonstrate higher engagement in conversation compared to those with higher response latencies. Moreover, effective turn-taking includes evaluating whether the participant is able to maintain a smooth conversation with the robot by answering its questions, asking questions themselves, or continuing the conversation. We do not take into account verbal fluency because our main focus group consists of PwD, who may have difficulties in this area. Moreover, silences during the interaction are expected as the participants are also painting; they may be silent because they are busy with this task.

Furthermore, following the concept of Altercentrism, we aim to study the involvement and interest of the participants during the interaction. In the interaction, the robot asks the participant questions such as "Why did you choose to paint this picture?" or "Do you like painting?" If the participant responds with short replies like "yes," "no," or "I don't know," it indicates lower conversational engagement. In contrast, higher engagement is demonstrated when the participant talks and shares details, thereby showing their involvement in the conversation. Moreover, the exchange of pleasantries and the friendliness of participants are also assessed during the interaction to study their engagement in conversation.

3.5.2. Task engagement

Oertel et al. suggest that task engagement can encompass any kind of human-agent interaction where behaviors are focused on completing a task [67]. RQ2 investigates the influence of the robot on the participant's engagement during a painting task. By analyzing the participants' paintings at regular intervals, we assess the parts they have painted and understand the robot's influence on their creative process. This approach ensures that the observed behaviors are focused on completing the painting task, thus aligning with the principles of task engagement as outlined by Oertel et al [67].

3.6. Research Design

Based on the research questions mentioned in Chapter 1, we dive deeper into the variables we want to study. The first research question is centered on developing a memory model for a social robot to enable meaningful conversations with PwD. The necessary variables to be studied are:

- Engagement in conversation
- Sense of companionship
- Valence of emotional state

Factors Influencing the Variables to be studied in RQ1:

- **Robot's memory model:** The memory model of a social robot greatly influences how it interacts with participants. By maintaining dialogue, customizing interactions from past conversations, and adjusting to the participant's style, the model supports more engaging exchanges. It also helps

the robot remember previous interactions, promoting a sense of companionship by making participants feel understood and remembered. Additionally, the robot's ability to recall and react to emotional cues positively affects the emotional tone of interactions, enhancing the participant's overall emotional experience.

- **Participant's perceived personalization of interaction:** If a participant feels that the robot recognizes and responds appropriately to previous interactions, this could lead to more enjoyable and effective communication.
- **Participant's level of trust in the robot:** the level of trust that participant has in the robot could also mediate outcomes, influencing how comfortable they feel during interactions.
- **Participant's mood during interaction:** The mood of the participant during the experiment could influence how they react to the robot's attempts at conversation. For instance, a participant in a negative mood might be more susceptible to feeling discomfort and unwilling to participate in conversation or painting activity.
- **Health of participant:** Physical ailments or discomfort can limit the length of time participants are willing or able to interact with the robot. This could impact the depth of engagement and the extent of data collected during each session. Moreover, physical health issues, such as hearing or vision impairments, can affect how participants interact with and respond to the robot.

The second research question focuses on examining participant's engagement during painting activities and interactions with the social robot. For this purpose, the variable of engagement in painting activities will be the primary subject of study.

Factors Influencing the Variables to Be Studied in RQ2:

- **Painting activity:** Participants who struggle to understand or utilize the painting application functionalities on the tablet might find the experience frustrating, which could negatively impact their overall engagement. Ensuring the application is user-friendly is crucial to maintaining positive engagement levels during the study.
- **Presence of a robot:** While some people might appreciate the companionship and guidance offered by the robot, enhancing their engagement with the painting activity, others may prefer to paint in solitude. Therefore, the presence of the robot and its conversational behavior could either positively or negatively affect engagement, depending on individual preferences for interaction during the painting activity.
- **Participant's cognitive engagement:** The level of cognitive engagement might mediate the impact of the art activity on overall engagement. If the activity successfully stimulates cognitive functions, it could lead to higher overall engagement.
- **Emotional Triggers Conveyed by Art Activities:** The emotional reactions triggered by art activities can significantly affect how engaged participants are. If the art activities resonate emotionally, they can boost participants' involvement and interest, leading to better engagement.
- **Participant's experience with painting and art:** Whether or not a participant has prior experience with art could moderate the impact of the art program. Participants with a background in art might engage differently compared to those without such experience.
- Furthermore, as discussed above, the mood and health of participants can also influence the engagement of participant in the painting activity.

My research began by examining which type of art activity is most effective in engaging PwD. Supported by substantial literature affirming the benefits of art activities, I structured my research into two primary segments:

- Developing a memory model to facilitate interactions during a painting session with PwD.
- Investigating methods to assess the engagement of PwD in the activity and conversation.

Initially, I conducted a comprehensive literature review to identify the most innovative and effective approaches for these two aspects. I aim to integrate state-of-the-art research into my work while simultaneously enhancing it.



Figure 3.1: Experiment setup

After completing the literature review, I moved on to the implementation phase, starting with the development of the memory model. Given its complexity, this aspect forms the core of my focus. In contrast, the development of the engagement assessment model will be more concise, owing to the limited time available for the research.

3.7. Experimental Design

The experimental design consists of the following steps that were strictly followed for every participant:

1. The experiment begins by explaining the contents of the consent form. Participants are given explanations regarding their roles during the experiment. Additionally, they are informed about an interview they will participate in after the session, where they will be asked questions about their experience with the robot during the painting activity. Due to ethical restrictions preventing the recording of audio during the interview, a transcriber was present to document everything discussed. Furthermore, they are told how their data will be used and are asked to sign a consent form.
2. Since the participants are not familiar with the painting application on the tablet, we demonstrate how to use the interface and the various tools available for coloring on the screen.
3. After this, the participant is seated in front of the robot with a tablet displaying an open painting application, as mentioned in Figure 3.1. The painting activity is conducted as described in Section 3.4.
4. Participants undergo a single session with the robot, and after the session, they are asked to participate in an interview. This interview helps in further evaluation of our system.

Figure 3.2 represents the complete experimental design.

3.7.1. Pilot study

Due to the limited availability of older adults to participate in the main experiment, the pilot study was conducted with students from TU Delft. Based on the feedback from the pilot study participants, the integration of episodic memory and visual short-term memory in a social robot positively influenced the interaction dynamics with participants. Participants generally reported enhanced engagement and a deeper sense of companionship during the interactions. Several noted the robot's supportive comments and its ability to maintain a conversation, though some wished for more proactive conversation initiation from the robot, particularly on diverse topics such as weather. The emotional responses were

largely positive, with participants often feeling more connected and emotionally supported during the interactions.

3.8. Evaluation strategy

Restating RQ1: **How does incorporating episodic memory and visual short-term memory in a social robot affect the following aspects during interactions with older adults?**

- **Engagement in conversation**
- **Sense of companionship**
- **Valence of emotional state**

Since RQ1 centers on the conversational aspect of social interaction, aiming to facilitate engaging conversations that offer a sense of companionship. Therefore, the three components of RQ1 have been further examined to understand their analysis:

1. **Engagement in Conversation:** As per our definition of conversational engagement in Section 3.5, we analyze the conversation between the robot and the participant. We focus on the following aspects of the participant's responses, with the corresponding baseline for high engagement:
 - **Response latency:** The participant responds promptly to the robot without any delay, thereby having a low response latency.
 - **Turn taking:** The participant is able to continue the conversation effectively by responding to the robot's questions, asking their own questions, or engaging in general conversation with the robot.
 - **Response type:** The participants' responses consist of more than one-word replies or simple 'yes,' 'no,' or 'I don't know' answers, thereby sharing details with the robot as part of effective communication.
 - **Friendliness:** The participants are friendly towards the robot.
2. **Sense of Companionship:** This will help us understand how well the presence of a robot can emulate companionship and fulfill social interaction needs for elderly people, potentially mitigating feelings of loneliness and isolation.
3. **Valence of emotional state:** The research will assess the intensity with which interactions with the robot provoke emotional responses. This will be measured by asking participants in the post session interview to report instances where they felt annoyed or emotionally triggered during conversations with the robot, providing insights into the emotional safety and effectiveness of the robotic interactions.

Table 3.1 summarizes the evaluation strategies for RQ1.

Restating RQ2: **How does introducing an art activity program facilitated by a social robot affect the engagement levels of older adults in the activity?**

Since RQ2 is centered on the painting activity, the most important element is the participant's engagement in the painting activity. As per our definition of task engagement mentioned in Section 3.5, task engagement can be studied by reviewing the paintings created by the participants. All the screenshots taken at fixed intervals during the painting session will be analyzed. Furthermore, conducting an interview at the end of the painting activity will provide insights into the effectiveness of the robot's presence. This will help assess how well the activity captivated the participants' interest and involvement, and how the robot assisted the participants in engaging with the painting activity.

To further evaluate how well the robot's dialogues align with the guidelines detailed in Section 3.1, a comprehensive analysis of the conversation database will be performed. This analysis will examine all responses generated by the robot to ensure they adhere to the specified guidelines. In addition to this, overall motivation will be assessed by tracking the total duration of the conversation between the participant and the social robot. Moreover, the efficiency of the robot's memory will also be assessed through the interview. Table 3.2 depicts all the metrics we aim to evaluate in this research and our methods of evaluation.

Important aspects of the research question	Analysis method	Baseline
Engagement in the conversation	Quality of response provided by the participant during the conversation with the robot	Prompt responses (response latency), effective conversation continuation (turn taking), detailed responses beyond simple 'yes,' 'no,' or 'I don't know' (response type), and friendliness towards the robot.
Sense of companionship	Interview	Participants experience a feeling of companionship from the social robot.
Valence of emotional state	Interview	Provide comfort to the participant and reduce frustration and emotional triggers.

Table 3.1: Analysis of RQ1 for evaluation

Metrics	Analysis method
RQ1	Studying conversation database and interview
RQ2	Interview and painting analysis
Efficiency of robot's memory	Interview and analysis of conversation database
Robot's adherence to guidelines for conversing with people with dementia	Analysis of conversation database
Overall motivation	Total time of painting activity
Feasibility of tablet use	Interview

Table 3.2: Metrics and their method of analysis

3.9. Design of Semi-structured Interview

A semi-structured interview was designed based on the methods of Adeoye-Olatunde et al. and Longhurst et al. [3, 55]. The steps are outlined below:

3.9.1. Step 1: Reason for incorporating semi structured interview

In RQ1, We aim to study the effect of incorporating episodic memory and visual short-term memory in a social robot for interactions with older adults. By enhancing conversations, we hope to create a sense of companionship and positively affect their emotional state. To properly assess these effects, semi-structured interviews are crucial. This interview style allows for deep exploration of older adults' experiences and opinions, providing detailed information that standard questionnaires might miss. With open-ended questions and flexible follow-ups, we can understand how these memory features in the robot enhance conversation quality, emotional connection, and emotional state changes [2].

Similarly for RQ2, introducing an art activity program led by a social robot requires understanding how older adults respond to it. Semi-structured interviews are ideal for this, as they let participants share their thoughts and feelings about the robot's role and their level of engagement in the painting activity. This method helps capture a wide range of perspectives and individual differences, explaining why

engagement might increase or decrease. Additionally, the conversational nature of these interviews helps build trust with participants, encouraging them to share more openly, which provides valuable personal stories and detailed feedback for a thorough evaluation.

3.9.2. Step 2: Participant recruitment

For this study, approximately 6-12 participants are needed. This number is ideal for a qualitative research approach [55], as we focus on obtaining in-depth and detailed insights into participant experiences and perceptions. With a smaller, manageable group, it is possible to conduct thorough individual interviews that allow each participant enough time to share comprehensive personal narratives and nuanced responses.

3.9.3. Step 3: Developing the semi-structured interview

Semi-structured interviews take into account an interview guide with questions designed to address the research objectives. Unlike unstructured interviews, the guide provides structure but is flexible, allowing the conversation to flow naturally. It includes open-ended main questions and follow-up probes, unlike closed-ended questions typical in surveys used for quantitative analysis [3]. Given below are the questions designed to address every aspect that we aim to study:

Interview questions for RQ1

The main question asked to address RQ1 is: **How did talking to the robot affect your experience during the painting activity?** Probing questions to further study the aspects of this research question are described in the Table 3.3.

RQ1 aspects to be studied for interview	Probing questions
Sense of companionship	<ul style="list-style-type: none"> • Did it feel like you were painting alone or as if you were painting with someone? • How did the robot respond to things you said during the painting? Did it seem to understand you?
Valence of emotional state	<ul style="list-style-type: none"> • Did you notice the robot reacting to your emotions while you painted? Can you explain a situation? • Was there ever a moment when the robot's actions or responses frustrated you? What happened? • How was your mood change during your interaction with the robot? • Did your mood change after interaction with the robot? How?

Table 3.3: RQ1 probing questions

The reasoning behind the choice of questions is described in Table A.1. The main question helps answer RQ1 by exploring the user's overall experience, which is further broken down through probing questions.

Interview questions for RQ2

The main question for this research question is: **Did you enjoy painting with the robot? What did you enjoy most?** The probing questions are described in Table 3.4

RQ2	Probing questions
<p>How does introducing an art activity program facilitated by a social robot affect the engagement levels of older adults in the activity?</p>	<ul style="list-style-type: none"> • Do you think having the robot there affected how long you spent painting? • If the robot wasn't there, do you think you would have painted differently or felt differently about the painting? • What aspects of painting with the robot did you find helpful? • Did the robot's suggestions influence how you painted? Can you describe how? • Did you feel that the robot's comments were relevant to what you were doing? Can you give an example? • How did the presence of the robot impact your interest in the painting activity? • In what ways did the robot motivate you to continue painting?

Table 3.4: RQ2 probing questions

The reasoning behind the choice of questions is detailed in Table A.2. The main question directly addresses the user's overall enjoyment and specific positive aspects of the painting activity. Enjoyment is a key indicator of engagement [5, 4], and understanding what participants enjoyed most can reveal which elements of the robot's facilitation were most engaging. The probing questions provide insights into how the robot facilitates deeper involvement and improves the overall painting experience for older adults. By asking about the influence of the robot's suggestions, the relevance of its comments, the impact on user interest, and the ways it motivated the user, these questions gauge the level of engagement in the activity.

Assessment of Robot's memory

In this section, the robot's episodic memory and visual short-term memory were separately analyzed. Table 3.5 refers to the main and probing questions used in assessment of the robot's episodic and visual short term memory.

The reasoning behind the choice of questions is detailed in Table A.3.

Interview question for tablet use

Another question was asked to the participants: **"How did you find using a tablet for painting? Was it comfortable for you?"**

This question aimed to determine whether the participants were comfortable using a tablet for painting or if they preferred the traditional method of using a paintbrush and paper. Understanding their preference helps us gauge the acceptability of painting on a tablet among our user group. Additionally, it provides insights into any potential barriers to using digital tools for creative activities, which can inform future improvements in designing user-friendly interfaces for older adults.

3.9.4. Step 4: Conducting interview

The participants were informed before signing the consent form that after the session, they would need to participate in an interview in order to share their experiences. While the interview format is flexible enough to accommodate the natural flow of conversation, it is strategically structured around specific questions that align with our research objectives. This ensures that the discussion remained focused and relevant to the aspects of the study we aimed to evaluate. These questions serve as a guide to direct the conversation towards crucial areas of interest while maintaining consistency in the flow of

Memory type	Main Question	Probing questions
Episodic memory	Did you feel that the robot remembered things from earlier in your conversation?	<ul style="list-style-type: none"> • How did it make you feel? • How did the robot's ability to remember affect your interaction? • Do you think the robot's ability to recall previous details made the conversation more personal? Why or why not?
Visual short term memory	Did the robot seem to know what you were painting?	<ul style="list-style-type: none"> • Did the robot make relevant suggestions to what you were painting? • Was the robot aware of your painting progress? How did it make you feel?

Table 3.5: Main and probing questions for Robot's memory assessment

conversation. This allows for a thorough investigation of each targeted aspect of the user experience with the robot.

3.9.5. Step 5: Analysis of interview

The analysis of the semi-structured interview was conducted systematically by integrating concepts from the work of Adeoye et al. [3]. Since the interview data was transcribed by the transcriber during the interview, this data was referred to for further analysis.

- **Data Cleaning:** The raw transcriptions were meticulously reviewed to remove irrelevant or extraneous information, ensuring that only relevant details were retained for analysis. Relevant details include conversations that have the potential to answer our main and probing questions. For example, a participant discussing their fear of robots is relevant. However, when they further discuss how robots in movies take over the world, this is not entirely relevant to our research question. Therefore, such details can be removed from the data to provide a clearer understanding of how the interview helps us answer our main and probing questions.
- **Coding:** The cleaned data was systematically coded to identify recurring themes, patterns, and categories. Responses were tagged with appropriate codes representing the main ideas or sentiments expressed by the participants. To identify the codes in the conversation, I carefully read through each response to the interview questions, focusing on key phrases and sentiments that reflect specific aspects of the participant's experience. I looked for repeated ideas, unique observations, and emotional reactions that could be categorized and labeled as codes. For example, in the response "Interaction was enjoyable", I identified the code "enjoyable interaction". This code captures the positive sentiment expressed about the overall experience of interacting with the robot.
- **Theme identification and Categorization:** All the codes were categorized based on the specific questions from Section 3.9.3, enabling a focused analysis of the themes or nature of the answers for each question. For example, the code "enjoyable interaction" helps us analyze the question: "Did you enjoy painting with the robot? What did you enjoy the most?"
- **Drawing conclusions:** The themes and patterns identified were interpreted to draw meaningful insights and conclusions as discussed in Section 3.10 to answer the research questions.
- **Reporting results:** The final results have been reported in section 5

3.10. Data analysis

Data was gathered in three forms in this experiment:

1. The conversation database consisted of all the interactions between the participants and the robot.
2. Screenshots of the paintings to study task engagement.
3. A detailed analysis of the interviews was conducted to evaluate all the questions mentioned in Section 3.9.3.

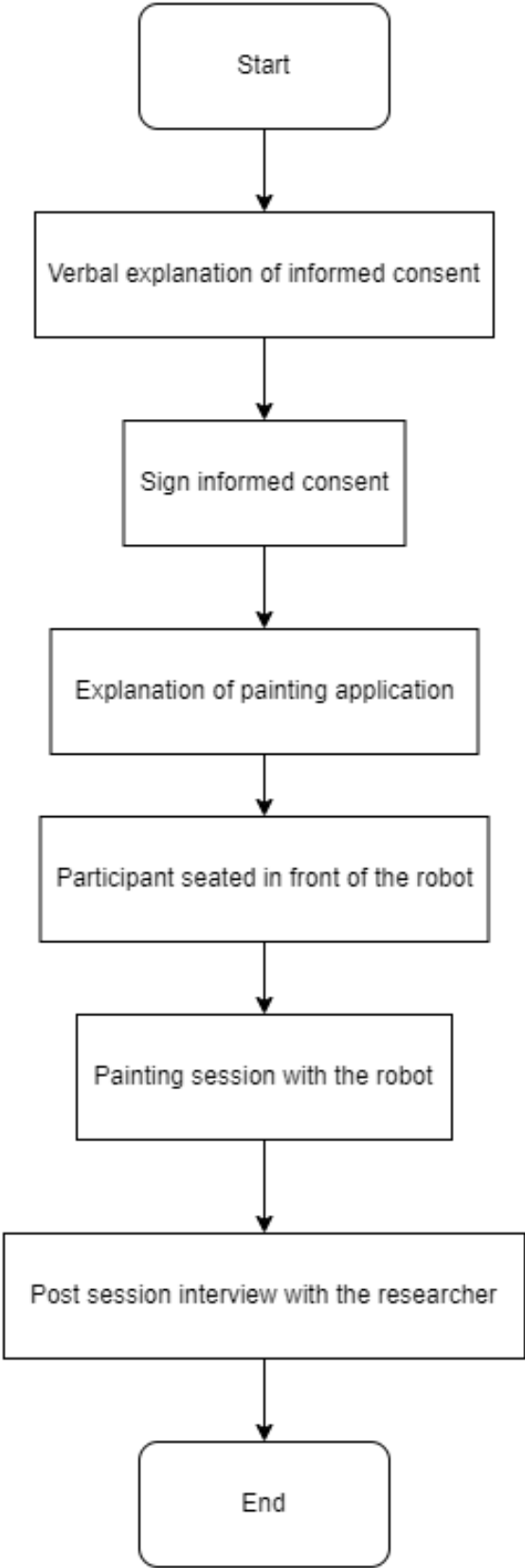


Figure 3.2: Experimental design

4

Technology and Implementation

4.1. Choice of robot

Initially, the Pepper robot was considered for use [70]. Pepper, a sociable robot, is designed for a broad spectrum of applications, including business-to-business (B2B), business-to-consumer (B2C), academic (B2A), and developer (B2D) interactions. Equipped with an array of sensors, a display, cameras, and wheels, Pepper possesses the ability to navigate its surroundings and engage with people effectively. Its versatility makes it suitable for deployment in a variety of environments such as homes, schools, shopping malls, care facilities, and airports, where it has already begun to make its mark. The deployment of Pepper in these environments underscores its significant potential to enhance daily life and operations, establishing it as a valuable asset in the evolving landscape of social robotics.

Establishing a connection with Pepper proved challenging due to outdated SDK connections and complex installation requirements on the current operating system (Windows). WoZ4U, a highly customizable interface for Softbank's Pepper robot [76], required Python 2.7, conflicting with the need for a newer Python version to incorporate advanced libraries for named entity recognition and leveraging large language models. An attempt to link the existing code with Pepper involved transferring data from the code via WebSockets to another program using WoZ4U. This approach, however, introduced additional delays in data transmission and increased system complexity. The SIC framework, created by researchers at VU Amsterdam, offers another interactive platform for Pepper, but its installation on a Windows operating system presented difficulties. Moreover, transferring all computational tasks to Pepper was impractical due to the robot's limited processing capacity, especially for demanding tasks like operating LLM.

To address the aforementioned issue, a different robot, Navel was introduced. Figure 4.1 represents the naval robot. Navel is a mobile social robot engineered to enhance interactions between humans and robots, focusing on both verbal and nonverbal communication abilities. Its design closely replicates human-to-human interactions, using an NVIDIA Jetson Xavier AGX as its core processor [85]. This allows Navel to efficiently process complex computer vision algorithms, enabling it to recognize and respond to social signals in real-time while prioritizing user privacy. The robot's innovative use of fiber-optic plates creates expressive, three-dimensional eyes, facilitating realistic eye contact and effectively communicating emotions and intentions during interactions.

To avoid the discomfort associated with the Uncanny Valley, Navel features an abstract humanoid design, making interactions more pleasant and engaging for users. Beyond verbal exchanges, Navel is attuned to nonverbal cues such as facial expressions and body language, enhancing its communication capabilities. This advancement in robotics opens up new opportunities for applications in settings requiring sensitive and empathetic interaction, such as elderly care and engaging with children.

Therefore, Navel is optimally positioned for the project focusing on conversational and interactive tasks with PwD, where its unique blend of verbal and nonverbal communication skills can significantly contribute. Thanks to Navel's robust ability to handle complex computations, the entire codebase can also be migrated to Navel, and the program can be operated exclusively on it, depending entirely on

Navel's processing power. Due to the robot being used by multiple researchers, the code is stored remotely and easily connected to the Navel robot via a socket connection.



Figure 4.1: Navel robot

4.2. Comprehensive System Overview

The system facilitated collaboration between two activities with the user: a painting activity and a conversation with the robot as discussed below.

4.2.1. Painting activity

The robot will be employed to interact with PwD and assist them in a painting activity designed for simplicity. This activity requires participants to use a tablet and stylus to color in pre-outlined images displayed on the tablet, where each section is labeled with a number. These numbers correspond to specific colors indicated on the sheet, a method known as "Paint by Numbers." Robot's role will be to guide the participants through the painting process, helping them with each step and directing them to the next one. Additionally, during the painting activity, the robot will engage the participants in conversations about the painting, enhancing their experience and involvement in the activity. An example of paint by numbers is given in figure 4.2.

However, since the original experiment was conducted with elderly adults, the complexity of the images was enhanced and no numbers were included on the images to be painted. Participants were offered a choice of three images, categorized as easy, medium, and difficult, from which they could select one to paint. As soon as the user begins painting, screenshots are periodically captured and transmitted to the local code on the laptop, which is used in the development of the robot's memory.

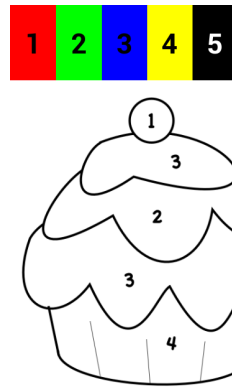


Figure 4.2: A typical example of paint by numbers

These screenshots act as a Short-term memory for the robot, enabling the robot to keep track of the user's painting activity, including the specific areas and colors being used. This information is then utilized by the robot to engage in discussions about the user's current progress in the painting.

4.2.2. Conversation Process

The conversation has been segmented into three distinct sections:

- **Initiating the conversation:** This section starts with the social robot greeting the person. It follows a simple script with phrases like, "Hello! My name is Milo. May I please know your name?" and "I understand! I'm doing okay! Would you like to paint with me today?" These scripted phrases are important because they help the robot to introduce itself and start getting to know the person. The initial conversation makes the person feel comfortable and familiar with the robot. It also allows the person to get used to the process that's taking place. By asking for the person's name, the conversation becomes more personal. This makes the person feel that the robot is speaking directly to them, rather than just any random user.

During the greeting session, the robot asks the user how they are feeling today. If the user indicates they are feeling down, the robot offers them the opportunity to discuss their feelings further. If the user chooses to elaborate, the robot listens attentively and acknowledges their emotions with appropriate responses, which are generated using large language models. After the user has finished discussing their issues, the robot redirects the focus back to the painting. This step is essential from the user's perspective because it helps establish a supportive and empathetic interaction, making the user feel heard and cared for. This emotional support can significantly enhance the user's comfort and trust in the robot, making them more likely to engage positively with the session. Moreover, this step also allows the robot to adapt its interactions based on the user's emotional state, enhancing its responsiveness and intelligence. The robot's ability to understand and react to the user's mood is essential for providing personalized support. This sensitivity is facilitated by storing these conversational exchanges in its episodic memory, which enables the robot to recall and use this information to tailor future responses appropriately.

- **Explanation of painting process:** After the initial greeting and the person agrees to paint, the robot helps them navigate through the painting application. The robot explains which buttons to press to move to the main painting process. The application is designed to be simple, making it easier to guide the user through it. There are three screens in the Android application: the welcome screen, the image selection screen, and the digital canvas screen. This step-by-step guidance ensures that the user feels supported and can easily proceed with their painting activity.
- **Establishing episodic memory for the robot:** At this stage, the person is using the tablet to paint, and the robot provides companionship. The robot has pre-programmed messages to initiate conversations and maintain engagement. Currently, the robot focuses on painting-related topics. It asks questions such as, "Which color would you like to start with first?" It also prompts

deeper reflection with questions like, "I'm curious, what feelings does this image by Vincent van Gogh evoke for you, and what made you choose to paint it?" and "Do you have any personal memories related to this painting?" These questions prompt deeper reflection on the painting and personal experiences, promoting a more personal and emotional connection. They encourage users to explore their feelings and memories, enhancing the interaction's emotional depth and meaning. By discussing personal experiences and emotions related to the painting, these prompts stimulate cognitive processes like memory recall and emotional reflection. Ultimately, the robot facilitates a deeper connection between the individual and their artistic creation through these questions.

The robot uses LLM to manage these conversations, acknowledging the person's feelings and appreciating their responses. It asks follow-up questions based on the person's responses. Additionally, the robot includes basic questions like, "Do you like painting?" and "What do you like in your painting?" These interactions help the robot build episodic memory with the person, enhancing the personal connection and making the interaction more meaningful.

- **Establishing short term memory for the robot:** In addition to its episodic memory, the robot also possesses a short-term visual memory. Every 45 seconds, the tablet automatically captures a screenshot of the current painting, which is then sent from the tablet to the robot. We selected a 45-second interval because, below this threshold, the robot struggled to effectively perceive differences between successive images due to minimal changes. Conversely, intervals longer than 45 seconds resulted in significantly widened gaps, potentially compromising real-time tracking efficiency. The received screenshots are stored in the short-term memory, with the system retaining only the last two screenshots while discarding older ones. Having the latest two screenshots enables the robot to initiate conversations about the changes occurring in the painting at regular intervals, thus keeping the robot informed about the user's progress.

This step is crucial because it allows the robot to provide timely and relevant feedback on the user's artistic development. By observing the changes between the two most recent screenshots, the robot can make specific comments or suggestions tailored to the user's current work, enhancing the interactive experience. This real-time tracking helps maintain a dynamic and responsive interaction, encouraging the user through continuous engagement and personalized support.

The awareness of the robot about the user's painting progress can evoke feelings of support and companionship in the user. Knowing that the robot is actively observing and responding to their creative process can make the user feel valued and understood. This perception of having a supportive partner in the creative journey might also enhance the user's confidence and motivation. The interactive feedback from the robot provides a positive emotional experience, making the painting session more enjoyable and fulfilling.

- **Utilization of memory model:** Once the robot's initial memory is established, it retrieves the highest-ranked memories, as further detailed in Section 4.3.5. These memories are then reformulated into questions. For example, if a user previously mentioned to the robot, "I like the painting *Starry Night* because it evokes a feeling of calmness in me," and this memory is highly ranked at a certain retrieval stage, the robot then uses this memory to pose a further question, such as, "What colors or shapes in *Starry Night* make you feel calm?"

Retrieving memory in this way is useful because it helps the robot create more meaningful and contextually relevant conversations. By referencing past interactions, the robot can build a sense of continuity and familiarity, which enhances user engagement. It also demonstrates the robot's ability to remember and consider the user's preferences and emotions, making the interaction feel more personalized and attentive. This method aims to deepen the user's connection with the activity, encourage deeper thought and reflection on their experiences, and improve the overall interactive experience with the robot.

- **Ending the activity:** Fifteen minutes into the session, the robot inquires whether the user would like to continue painting or end the session. If the user decides to paint more, the robot continues to offer companionship as before. However, if the user chooses to end the session, the robot gracefully wraps up the interaction.

A detailed description of the system architecture is provided in Section 4.3. This section offers an in-depth look at the conversation process.

4.2.3. Design of Conversation

Based on the guidelines mentioned in Section 3.1, the conversation has been specifically designed to cater to the needs of PwD in the following manner:

- **Clarification:** Using episodic memory, the robot asks the person for clarification in the form of a question.
- **Exploration:** To understand the views or preferences of the person, the robot asks some predefined questions. These questions include:
 - Which color would you like to start with?
 - Do you like painting?
 - What do you like about your painting?
 - Do you like your painting so far?
- **Moderation:** The robot introduces new topics for discussion by asking questions such as:
 - I'm curious, what feelings does this image by Vincent van Gogh evoke for you, and what made you choose to paint it?
 - Do you have any personal memories related to this painting?

However, these questions also serve as a method of exploration, as the robot tends to ask the person questions to understand their views and preferences. Moderation is achieved by commanding the robot to stick to discussing painting at all times and not stray from this topic. This helps in managing the direction of the conversation. More details about the technological aspects of response generation are mentioned in Section 4.3.6.

- **Validation:** Validation is performed in two ways:
 - Short-term memory is used to track the painting progress of the person, and then this memory is used to provide feedback and validate their painting progress.
 - The robot acknowledges the person's responses and supports their decisions or concerns, ensuring the person feels understood and valued. This positive reinforcement helps build trust and encourages further engagement.
- **Rescue:** The robot is guided to make suggestions to the person when they need help. Details regarding the technical aspects of this guidance are mentioned in Section 4.3.6.
- **Showing love and support:** The robot's speech was designed to provide a comforting experience to the person by expressing love and support during conversations. The technical implementation of this is detailed in Section 4.3.6.
- **Providing clear and simple message:** The robot is designed to provide clear and simple messages that are easy for PwD to understand. Therefore, the robot was programmed to always respond in 1-2 sentences.

4.2.4. Conversation flow

Based on Sections 4.2.2 and 4.2.3, a conversation flowchart has been designed, as shown in Figures B.4, B.5 and B.6. Figure B.4 shows the initial scripted conversation between the robot and the user. As the user mentions the color they want to paint with first, the LLM is used to continue the conversation, as shown in Figure B.5 and Figure B.6. In Figure B.5, the robot asks some questions like: "I'm curious, what feelings does this image by Vincent van Gogh evoke for you, and what made you choose to paint

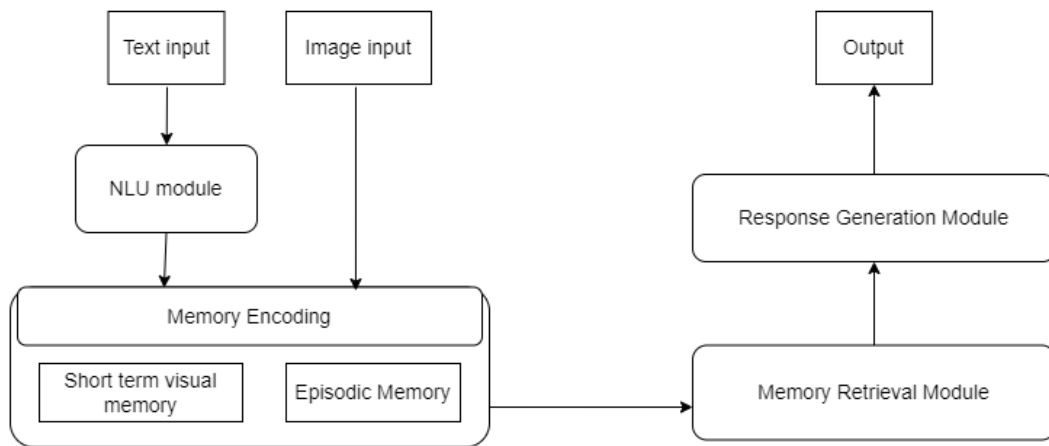


Figure 4.3: System architecture

it?” and “Do you have any personal memories related to this painting?” Questions like these help the robot gain deeper insights into the user’s connection to the painting.

Furthermore in figure B.6, to gather more data and build the robot’s memory, questions like “Do you like painting?” are asked. Moreover, when the robot detects silence or wants to direct attention towards painting-related topics, it either asks random seed questions or makes statements chosen from the conversation design strategy outlined in Section 4.2.3. These conversations, also known as seed messages, include:

1. “Do you like your painting so far?”
2. “What do you like about your painting?”
3. “Would you like me to give you some suggestions for your painting?”
4. The robot can retrieve the highest-ranked statement for future conversation.
5. The robot can compare two screenshots from the tablet to discuss the user’s painting progress.

Finally the end of conversation is also depicted in Figure B.6.

4.3. System Architecture

The system architecture has been divided into 6 parts:

- Input-output
- Natural Language Understanding Module
- Memory Encoding
- Memory Retrieval
- Response generation

Figure 4.3 refers to the system architecture

4.3.1. Input-output

Given that the study includes a painting activity and an interaction with a robot, a key limitation is the absence of speech recognition during these interactions. This decision was made because the robot

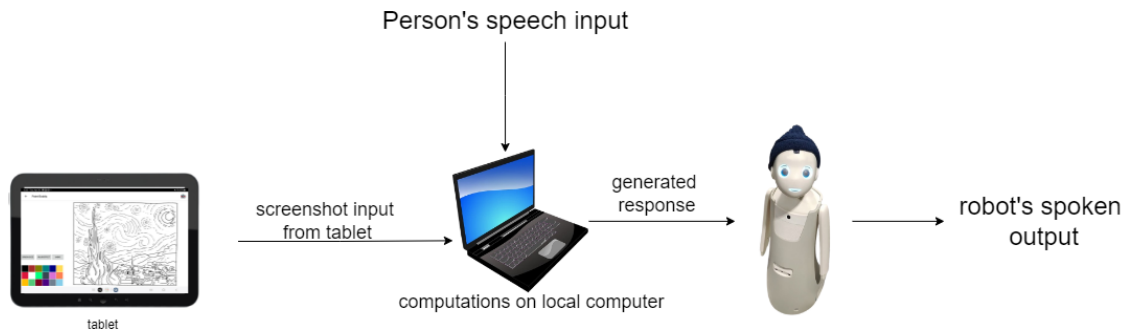


Figure 4.4: Input/Output setup

uses the user's input to form memories, and inaccuracies in speech recognition could create faulty memories.

A mechanism for input and output is crucial for interacting with the system. The system is designed to interact with users through two primary inputs and produces one output. The first input is textual data manually entered by users, which captures their responses to the robot's prompts. The second input comprises screenshots from a tablet, which are used by the system to create short term memories. The output is the spoken response from the robot, which is generated based on the processed inputs.

Throughout this process, the Wizard of Oz technique is employed, where the user's spoken words are discreetly typed into the input interface rather than using speech recognition. These inputs are processed by the system, which generates a response. This response is then transmitted to the robot through socket connections, enabling the robot to speak. During the entire session, this socket connection is established between the remote code on a laptop and the robot. The robot acts as the server, continuously listening throughout the conversation to facilitate real-time data transmission. Meanwhile, the code running on the local computer functions as the client side. The complete setup has been depicted in Figure 4.4 This setup ensures seamless and precise communication between the computer and the robot, enhancing overall interaction quality.

4.3.2. Natural Language Understanding Module

Only the text input goes through this module. Once the user's response is entered into the system, it processes and interprets what the user said to form memories and generate an appropriate reply. Additionally, the beginning of the conversation is scripted to guide the user towards the painting platform based on their responses. Consequently, the system needs to comprehend the user's natural language instead of relying on keyword responses to effectively follow the script.

One way of implementation can be done using a list of dictionaries to provide different stages or steps in a scripted conversation. However, this technique has limitations in user response diversity. Hence, Natural Language Understanding (NLU) is employed to comprehend input in a more nuanced manner. In the field of computational linguistics and artificial intelligence, NLU is regarded as a crucial goal. According to Madeleine Bates, NLU is akin to the "Holy Grail" for researchers striving to enable computers to interact intelligently through human language, one of the most intricate aspects of human behavior [7]. Thus, pre-trained BERT NER was initially employed to tokenize and identify the first name of a person in the conversation. The name is specifically extracted at the beginning of the conversation to add a personal touch to the interaction. Additionally, sentiment analysis is used to assess each user input and generate a corresponding system response. This approach helps to bypass the need for a restrictive and limited list of keywords.

However, BERT struggled to recognize tokens accurately, particularly with names in the conversation. The model failed to identify real names correctly, often returning NULL values for complex names or generating abbreviated versions. This could be offensive to individuals interacting with a social robot that incorrectly addresses them by name. To address this issue, pre-trained RoBERTa has been used. Since RoBERTa is trained on a dataset that is ten times larger than the one used for BERT and utilizes

larger mini-batches during training, it is exposed to a wider variety of training examples in each step [54]. As a result, RoBERTa is more successful in correctly recognizing names.

For each user response, the system categorizes the sentiment as "positive," "neutral," or "negative." These categorizations are based on the emotional content of the responses, which are saved following the user's reaction to the system's initial prompt. The RoBERTa model then uses this understanding to steer the conversation along either a positive or negative pathway, depending on the detected emotion. A Python dictionary is utilized to manage this process. The initial part of the conversation is scripted, and the script is matched against each system prompt. The emotion of the user's response is analyzed, and based on whether it is positive, neutral, or negative, the direction of the conversation is accordingly adjusted.

If the system prompt matches a predefined script, the system follows a specific path; otherwise, it employs a large language model (LLM) to generate responses. In the code below, once the system prompt is found, it first checks if the user's response was positive, neutral or negative to the system's prompt. Based on the emotion, the system checks conversation stages and gives the appropriate response:

```

1   if re.search(re.escape(stage["system_prompt"].format(user_name=user_name)),
2   last_system_prompt, re.IGNORECASE):
3       if sentiment == 'positive' or sentiment == 'neutral':
4           return generateLLMresponse(user_input, history, PRE_PROMPT_TYPE1,
5   PRE_PROMPT3)
6       elif sentiment == 'negative':
7           return stage["negative_response"].format(user_name=user_name)
8
9   conversation_stages = [
10  {"system_prompt": "Hello {user_name}! How are you?", "positive_response": "I
11  understand! I'm doing okay! And would you like to paint with me today?",
12  "negative_response": "I understand! Would you like to talk more about it?"}]

```

4.3.3. Memory Encoding: Episodic memory

The system consists of two types of memories: episodic memory and visual short-term memory, which are discussed in detail below. Every user response and system prompt is stored in episodic memory along with variables: emotion, relevance, and recency.

Emotion

This variable captures the type of emotion conveyed by the response, as determined by sentiment analysis using a pre-trained BERT-based sentiment model. This model classifies the response as positive, negative, or neutral. The exact value of emotion is calculated based on this classification: positive and neutral responses are depicted as +1, while negative responses are assigned a value of -1.

Recency

Recency is calculated to determine how recently a piece of information or a conversation was last accessed. This calculation is critical for ensuring that more recent interactions are given appropriate weight, influencing the system's responses and decision-making processes effectively. The system determines the recency score of a memory by measuring the time elapsed since it was last accessed. This score is computed using an exponential decay formula:

$$recency_score = e^{-hours_passed \times decay_factor} \quad (4.1)$$

The exponential decay formula used here to calculate recency mimics the natural fading of human memories over time. In cognitive psychology, this phenomenon is described by the "forgetting curve,"

which hypothesizes that memory retention declines exponentially with time unless the information is consciously reviewed [93]. Therefore, this method ensures that more recent interactions retain higher relevance, gradually diminishing the influence of older data.

Relevance

Relevance measures the importance of a conversation within the context of ongoing interactions. By assigning a relevance score to each conversation, the system can determine which past interactions should influence current and future dialogues. Relevance is computed using a method that leverages semantic embeddings and cosine similarity. This technique allows the system to understand and quantify the importance of a user's input in relation to the conversation's historical context. Below is a detailed breakdown of the method used for calculating relevance:

- **History Aggregation:** The system begins by combining all previous conversation into one block of text. This combined text acts as a context for assessing how relevant the new user input is.
- **Embedding Generation:** Both the combined history text and the new user input are separately converted into dense vector representations using pre-trained BERT model. This process includes:
 1. Tokenize the input text using the BERT tokenizer.
 2. Pass the tokenized inputs through the BERT model to obtain the output embeddings.
 3. These embeddings capture the meaning of the text, enabling calculations that measure how similar texts are to each other.
- **Cosine Similarity Calculation:** Cosine similarity is used to compare the embeddings of the historical text and the user input. It calculates the cosine of the angle between two vectors in a multi-dimensional space, providing a measure of how similar the two texts are. The process involves two main steps:
 1. Reshaping the embedding arrays to ensure they are compatible for operations.
 2. Calculating the cosine similarity score between the two vectors by taking the dot product of the embeddings and dividing by the product of their norms.
- **Relevance score:** The resulting cosine similarity score serves as the relevance score. A higher score indicates that the new user input is more relevant to the context of the previous conversation, suggesting that it can have a more significant impact on the ongoing dialogue.

4.3.4. Memory Encoding: Short-term memory

The images received from the tablet function as short-term memory for the robot. These images are screenshots captured from the tablet while the user is painting. The screenshots are taken and transmitted to the robot's memory via a socket connection every 45 seconds. Only the two most recent screenshots are retained in the robot's memory; older images are deleted. Based on these recent images, the robot gains an understanding of the changes the user has been making, allowing it to receive live updates on the user's painting progress. The technical details of how the robot generates responses by comparing two images are discussed in Section 4.3.6.

4.3.5. Memory Retrieval Module

The three most important aspects of memory are encoding, remembering, and forgetting. The encoding of memories has already been discussed in Sections 4.3.3 and 4.3.4, while the forgetting of memories is handled minimally using a decay factor to gradually diminish memories. Moreover, memory retrieval is the most critical component here for the robot, as it enables more meaningful interactions with the user. An intelligent system must be capable of recalling specific memories at the right moments, determining what to say based on the memories it has formed. This feature is essential for creating relevant and contextually appropriate responses during interactions. Memory retrieval is performed in two ways here: scripted retrieval of responses and retrieval of the highest-ranked memory.

Scripted retrieval of responses

In the initial stages of the conversation, the robot adheres to a scripted flow, greeting the user and guiding them through the painting process. This is achieved by defining conversation stages that script the robot's responses based on the user's replies. For example, if the robot asks, "Would you like to paint with me today?" and the user responds with "yeah sure," the robot continues with a positive scripted response, saying "Great! Do you have your painting tools with you?" Conversely, if the user declines to paint, the robot follows a negative scripted response: "I understand! Please call me back when you want to paint." This scripted flow is essential at certain stages of the conversation to ensure that the robot directs the activity in a specific direction and does not respond with irrelevant or out-of-context remarks.

Retrieval of highest ranked memory

Retrieval of the highest-ranked memory is a crucial aspect of this design. The retrieval process aims to minimize stress in conversations and make the user feel more comfortable with the system. Appropriate retrieval of memories is essential because it helps establish a bond with the user by ensuring that interactions are relevant and sensitive to their feelings and context.

As discussed in Section 4.3.3, all conversations are stored in episodic memory along with parameters emotions, recency, and relevance. These parameters are used to calculate the rank of each memory, and the highest-ranked memory is retrieved when the robot detects silence during the conversation or needs to steer the topic back to previous discussions to get clarifications on what the person said before. This serves as a method for engaging with a PwD, as discussed in Section 3.1. The rank of every response can be calculated by the equation:

$$rank = (relevance + recency) \times emotion \quad (4.2)$$

However, the goal is to recall memories that do not trigger the user. In our approach, both positive and negative emotions influence the ranking of user responses, with positive and neutral sentiments assigned a value of +1, and negative sentiment assigned a value of -1. When generating ranks for user responses, we only consider those with positive values for retrieval. By prioritizing positive memories, we aim to avoid recalling negative experiences that could create an uncomfortable environment. However, it is important to recognize that not all negative memories are equally triggering. For example, a statement like "I do not like potatoes" is categorized as negative by the sentiment analysis module, just as "my best friend died yesterday" is. However, the emotional impact of these two statements is vastly different. Thus, there is a need for a mechanism to filter out highly sensitive responses. Recalling a user's dislike for potatoes can be appropriate for casual conversation, whereas bringing up the loss of a best friend can be highly distressful and should be avoided unless it's relevant to the context and handled with care.

Importance: To differentiate between highly sensitive negative memories and more mundane negative memories, we assess the importance of the user's response. This is done using LLM, which receive a pre-prompt: "On a scale of 1 to 10, where 1 is purely mundane (e.g., brushing teeth, making the bed) and 10 is extremely poignant (e.g., death of a friend or personal trauma), rate the likely poignancy of the following piece of memory. Rate: "

This approach is inspired by the methodology described in [71] for calculating the importance of a user's response. We have chosen Mixtral as the LLM for this task due to its strong reasoning capabilities [37]. As we are considering all positive responses and only need to filter some negative ones, to save computational resources, importance ratings are only calculated for responses identified as negative by the sentiment analysis module.

Once the LLM provides a rating for the importance of a negative response, any responses with a value of less than 4 (importance threshold) are considered for memory retrieval, while those rated higher are excluded. We chose an importance threshold below 4 because different inputs were given to the LLM to provide a score. In almost all instances, the LLM scored non-important things below 4. This ensures that while all negative responses remain in memory, the more distressing ones are not retrieved in conversations, maintaining sensitivity and appropriateness in user interactions.

Therefore, we adjust the emotion based on the the value of importance as shown below:

$$adjusted_emotion = \left\{ \begin{array}{ll} +1 & \text{if emotion is positive} \\ +1 & \text{if emotion is negative and importance} < \text{importance threshold} \\ -\infty & \text{otherwise} \end{array} \right\} \quad (4.3)$$

Now, this adjusted emotion value is incorporated into Equation 4.4 to calculate the rank of the user's response as shown below:

$$adjusted_rank = (relevance + recency) \times adjusted_emotion \quad (4.4)$$

The adjusted rank is used to calculate the rank of all the user's responses, and the response with the highest rank is retrieved when needed.

4.3.6. Response generation

Response generation occurs in various ways within this system, as mentioned below:

Scripted retrieval of dialogues

At specific points in the conversation, such as during the initial greeting or when the robot assists the user through the painting application, a scripted response is retrieved from memory, and the robot replies in accordance with the ongoing dialogue with the user.

Seed messages

Seed messages are the set of messages that enable the robot to start a conversation with the user. The seed messages used in this system as mentioned in Section 4.2.4. These messages are crucial for gathering information from the user, which is then stored as episodic memories. The formation of these memories is beneficial because it provides the robot with sufficient data to engage in relevant conversations with the user later during the painting session. Additionally, by utilizing these details later in the conversation, the robot demonstrates active listening, ensuring its responses are appropriate and pertinent. This enhances the interaction by showing the user that the robot is attentive and capable of maintaining a coherent conversation instead of providing random, irrelevant responses.

Response generation for the retrieved highest ranked memory

As mentioned in Section 4.3.5 on the retrieval of the highest-ranked memory, once the highest-ranked memory is retrieved, it is utilized to facilitate communication with the person. Furthermore, as noted in Section 3.1, clarification is crucial when interacting with PwD, ensuring that their communications are understood through repetition. Therefore, once the highest-ranked memory is retrieved, it is reformulated as a question to request further information from the user. This approach aids in clarifying the information provided by the user and fosters meaningful conversation.

To implement this, the highest-ranked response is given to the LLM with the following prompt:

```
"You are Milo, a small robot designed to assist with digital painting.
You always engage in a cheerful and conversational manner. Your responses
should be concise, simple, and never exceed one sentence. For the following
task, convert the given statement into a straightforward question,
focusing on clearly identifying and requesting the missing information."
```

When this prompt is used with the highest-ranked statement, the LLM generates a response by rephrasing the statement into a question that seeks missing information. For example, if the highest-ranked statement is, "I loved to paint with my granddaughters; they used a lot of colors," the robot, following the prompt, might ask, "What colors did your granddaughters use in their paintings?"

This technique helps the user feel more engaged with the robot, as it asks relevant questions based on remembered interactions. Additionally, we avoid having the robot repeat the highest-ranked memory

verbatim. Instead, the memory is framed as a question, prompting the user to provide the missing information. This approach encourages cognitive engagement, enhancing the user's experience and connection during the conversation. By asking questions related to personal experiences or requiring recall of details, the robot stimulates cognitive processes. This can be especially beneficial for PwD, as engaging with memories can help improve their cognitive functioning [95]. Moreover, asking meaningful questions based on the user's past interactions deepens the conversation. It moves beyond superficial topics, encouraging users to think more deeply and express more complex ideas and emotions. This depth can make the interaction more satisfying and enriching for the user.

Response generated for painting progress

The robot discusses its short-term memory, which consists of images received at intervals. It explains the differences between two images, noting that the second image was captured 45 seconds after the first. This allows the robot to observe the user's progress by comparing the two images. Consequently, the robot comments on the new elements the user has added to the painting during that 45-second interval.

This is accomplished using the multimodal capabilities of the Google Vertex API (Gemini). Initially, the two images are encoded in base64 format, a method that transforms binary data (such as image files) into a string of ASCII characters. This format simplifies handling in text-based data transmission scenarios. Each encoded image is then encapsulated within a 'Part' object. The 'Part' class in Google Generative Models is designed to manage different types of content within a multipart message structure. It supports various data formats, including text, images, videos, and responses from function calls, making it suitable for use in generative models and other processes. The use of the 'Part' object for sending and analyzing image data is crucial here because it standardizes the handling of diverse data types, such as images and text, ensuring that both images and prompts can be easily integrated into the system's workflow.

The two image parts and a prompt are then sent to the Google Gemini model. The prompt is:

```
"You are Milo, a small robot designed to assist with digital painting.
You always talk in a conversational manner as a cheerful and fun robot.
Your responses should always be concise and in simple English, never exceeding
one sentence. You specialize in colors and art, especially in Van Gogh's
paintings. Currently, the user is painting: \{current\_painting\}.
Carefully observe and discuss any new changes or new elements that you
notice between the first and the second image. Offer compliments and validate
the user's progress in painting, keeping the tone light-hearted and engaging."
```

This prompt serves two purposes. First, it encourages the robot to discuss the differences in the painting, helping the user recognize that the robot is aware of their painting progress. Second, it focuses on complimenting the user and validating their efforts. Validation is a crucial aspect when communicating with PwD, as discussed in Section 3.1.

At the beginning of the conversation, the robot asks the user which painting they are working on, and the name of the painting is then passed to the models as *{current_painting}*. The Gemini model is expected to analyze the differences or notable features between the two images based on the visual data encoded within them and then provide a relevant response.

General response generation for conversation

All responses generated, apart from those previously mentioned, are created using an LLM through the Google Vertex API (Gemini) to ensure relevance and coherence. To focus the responses more accurately on the ongoing conversation, the last 20 interactions between the user and the system are considered as historical context, and the new response is generated based on these interactions.

The specific prompt used here follows the guidelines for conversation with PwD:

```
"You are Milo, a small robot designed to assist with digital painting. You
always communicate in a conversational manner as a cheerful and fun robot."
```

You specialize in colors, art, and specifically Vincent van Gogh's paintings. You converse with the user while they paint on a tablet, always giving concise responses in simple English. Currently, the user is painting: `\{current_painting\}`. Validate the user's comments about their digital painting without asking questions. You never initiate questions; you listen to the user. Only when asked, suggest painting techniques suitable for tablet use. Recommend basic colors from the palette, like black, blue, green, yellow, red, and pink. Do not suggest complex color names. Available brush sizes range from small to large. An option to use a blur effect is also available in sizes small, medium, and large. Only give suggestions based on the provided details and only when asked. Do not offer any suggestions other than those mentioned for colors, brush sizes, and one blur effect. Be attentive to emotional discussions about the artwork, ensuring the user feels understood. Focus on painting-related topics, and maintain a pleasant tone throughout the conversation."

Explanation of Specific Sections of Prompts Curated for Conversations with PwD:

- **Use of concise response:** Concise responses are crucial for individuals with dementia, as emphasized in section 3.1.
- **Current Painting Personalization:** Since the prompt highlights the robot's expertise in Van Gogh's paintings, mentioning the specific painting that the user is working on personalizes the conversation. This allows the robot to make relevant suggestions about colors and techniques that could enhance the user's painting experience. With this specific information, the robot can tailor its advice to the tools available on the tablet, ensuring that all suggestions are practical and immediately applicable.
- **Restricted Interaction Style:** By instructing the robot not to ask questions but to validate and provide suggestions only when asked, the interaction is simplified and directed. This is particularly helpful for PwD, as it reduces cognitive load and confusion, making the conversation more manageable and less overwhelming.
- **Specific Tool Suggestions:** Specifying which colors and tools to suggest ensures that the robot's guidance is based on the actual resources available to the user on the tablet they are painting on. This prevents confusion or frustration from suggestions that cannot be implemented, which is crucial for maintaining a smooth and positive interaction with individuals who may struggle with memory or decision-making challenges.
- **Emotional Support:** Being attentive to emotional discussions about the artwork helps in creating an empathetic interaction environment. For PwD, this supportive engagement is vital as it enhances their emotional well-being and encourages continued engagement with the activity.
- **Focus on Painting-Related Topics:** Keeping the conversation focused on painting helps maintain the user's attention on the task at hand, which can be beneficial for cognitive engagement. This focus also prevents the introduction of potentially confusing topics that might distract or disorient the user.

4.3.7. Choice of LLM in response generation

The initial implementation utilized Llama2, favored for its open-source accessibility, which simplifies customization and modification. However, this approach was ultimately abandoned due to the model's tendency to produce irrelevant and off-topic responses, such as inexplicably discussing HIIT exercises during conversations about paintings. The next attempt involved Mistral AI and Mixtral AI, another open-source option. Mistral excelled in calculation of importance due to its superior reasoning capabilities, but it fell short in conversation tasks, often generating excessively lengthy responses despite the requirement for brief texts suitable for PwD.

The search for an effective solution led to considering OpenAI's models, which, although promising, were set aside due to their subscription costs. The quest concluded with the adoption of Gemini Pro by Google, which surpassed other models in generating relevant conversations without significant hallucination. Additionally, the project's integration of painting with conversation highlighted Gemini's

multimodal capabilities, enabling it to provide insights based on paintings. This feature proved beneficial for engaging discussions about the art being created. Gemini Pro's comprehensive advantages thus made it the preferred model for the project.

4.4. Painting application: PaintBuddy

To create the platform for the painting activity, an Android application called "PaintBuddy" was developed. The PaintBuddy Android application serves as a digital painting platform where users can engage in a dynamic painting experience using pre-outlined images.

4.4.1. App specifications:

The application was developed on Android Studio using Kotlin as its main language. The app is suitable for installation on tablets with Android version 13 (Tiramisu) or higher.

4.4.2. App architecture:

The app's architecture is structured around several key activities that facilitate the painting process, enhance user interaction, and manage navigating through the application. The key components and features of this application are:

1. MainActivity

The MainActivity serves as the entry point of the application, presenting the main interface. It is designed with user accessibility in mind, incorporating a toolbar for easy navigation and a central button that initiates the painting session by navigating to the next screen "ImageSelectionActivity".

Features and Functions:

- **Toolbar:** Utilizes the AndroidX library for backward compatibility.
- **Button:** Initiates activity transitions using Android's Intent system, in order to move to the next screen.

Figure 4.5 shows the welcome screen for the painting application.

2. ImageSelectionActivity

This activity lets users select the complexity of the image they want to paint (easy, medium, or difficult). Each option is displayed with a button and a preview image. The buttons have large text for easy readability. Additionally, when the user enters this screen, a robot explains the three painting options, enhancing user engagement and offering a personalized painting experience.

Figure 4.6 depicts this screen in the painting application.

Features and Functions:

- **RelativeLayout and ConstraintLayout:** These layouts provide flexible and efficient ways to arrange and size the UI components dynamically.
- **ImageView:** Displays the image previews, utilizing the clickable and focusable attributes to improve UI interaction.

3. PaintActivity

PaintActivity is the heart of the painting experience in PaintBuddy, where users interact directly with the digital canvas to paint. It handles several key functionalities:

- **Displaying the Selected Image:** The activity loads and displays a user-selected image as a base for painting, making use of the ImageView component.
- **Paint Operations:** This screen provides with various paint operations as mentioned below:
 - **Color palette:** The color palette includes 18 colors, offering a broad range of shades to paint with. It features various shades of blue, green, yellow, orange, red, and more.

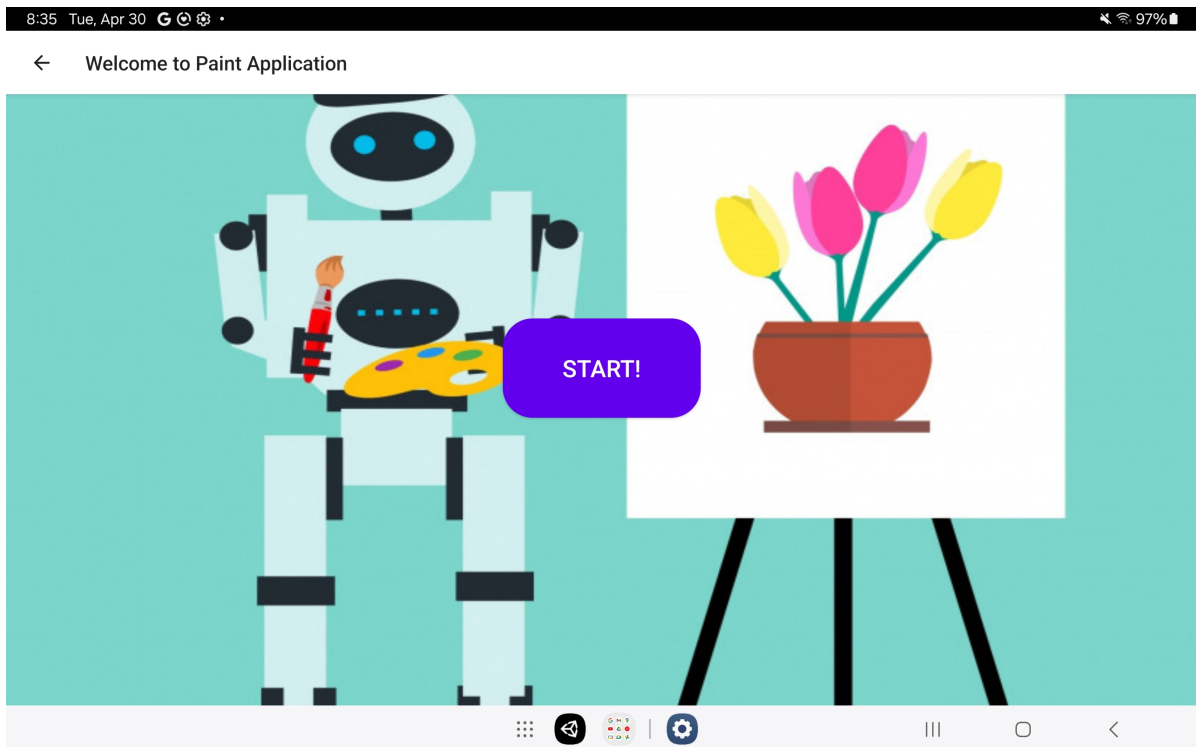


Figure 4.5: Entry screen of paint application

- **Undo button:** If the user makes a mistake while painting, they can use the undo button to reverse the last changes they made.
- **Brush size:** Three brush sizes—small, medium, and large—are available in the application to enhance the painting experience. Different brush sizes enable varying levels of detail; a small brush is ideal for fine details, while a larger brush can fill in broader areas. Using a large brush is also efficient for covering large surface areas quickly. These varied sizes allow users to express different artistic styles and adapt to different subjects more effectively.
- **Blur effect:** The blur effect is included in the painting tools to enhance various aspects of a painting. It helps create depth and focus by softening areas that appear further away, mimicking how distant objects are perceived in real life. For example, in a painting “The Starry Night” 4.7, applying blur effects to the stars and sky can enhance the artwork. This technique also helps convey the emotional intensity of the scene, adding a dreamlike or ethereal quality that can evoke feelings of wonder viewer.
- **Screenshot functionality:** A screenshot is taken every 45 seconds on this screen to track the user’s progress and send it to the robot.

The interface is designed to be simple and easy to use, minimizing confusion for the users. Figure 4.7 represents this screen in the painting application.

Features and Functions:

- **Button Interactions:** It contains buttons that trigger various functionalities like undo, changing brush size, and applying blur effects. Each button uses event listeners (*setOnClickListener*) to handle user interactions and modify the painting behavior.
- **Handler and Runnable for Screenshots:** Utilizes Android’s Handler and Runnable to periodically execute tasks, in this case taking a screenshot every 45 seconds.

4. PaintView

PaintView is a custom component derived from android component *View*, designed to handle the core drawing logic. All the features of PaintActivity work directly with the PaintView to update the painting.

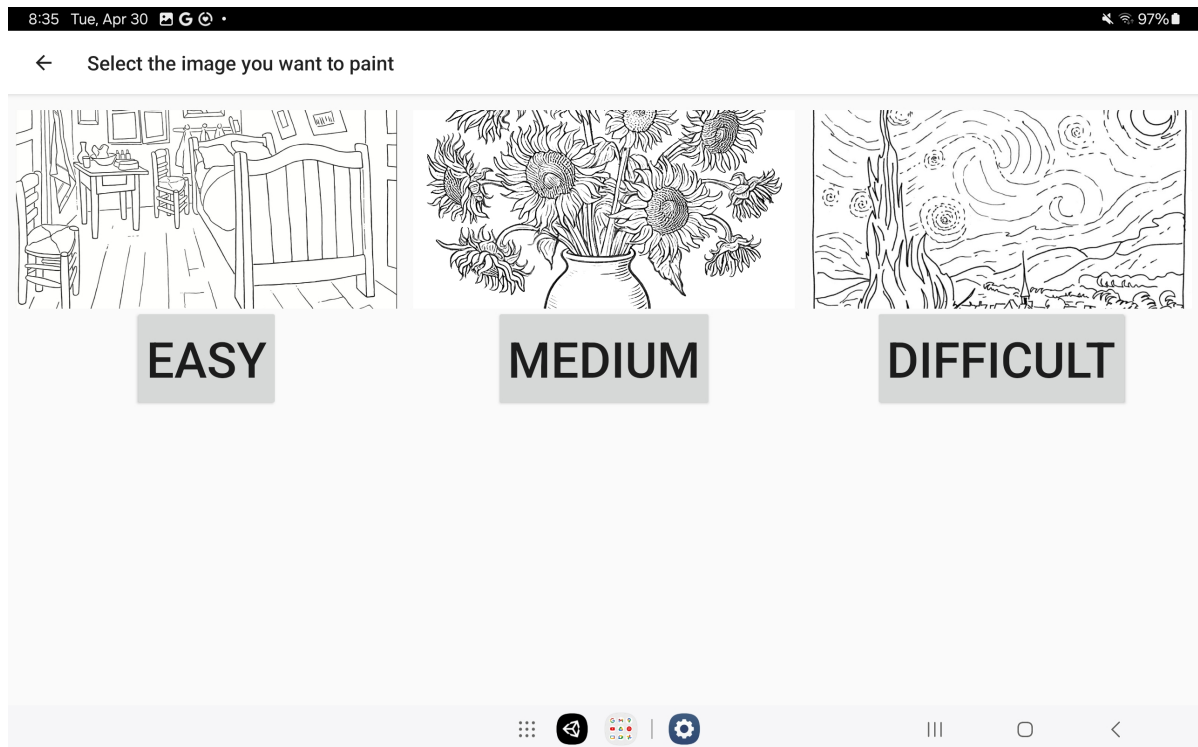


Figure 4.6: Image selection screen of paint application

Core components:

- **Custom Drawing:** Manages touch events (`onTouchEvent`) to draw on the canvas. It tracks user touch paths with the `Path` object and uses `Paint` to define drawing styles and colors.
- **Path Management:** Stores each stroke as a combination of `Path` and `Paint` objects, allowing for various painting actions. This also aids in the undo functionality, as all paths are stored with their colors, making it easy to remove the last created path (painted area).
- **Effect Application:** Adjusts paint properties to apply effects such as blur, enhancing the creative tools available to the user.

Efficient handling of drawing operations:

- **Use of Path and Paint Objects:** The `PaintView` maintains a list of paths (`MutableList<Pair<Path, Paint>>`), where each `Path` object represents a drawing stroke made by the user, and each `Paint` object defines the visual properties of that stroke, such as color and thickness. This method is efficient because:
 - It separates the drawing data (`Path`) from the rendering properties (`Paint`), allowing for more organized management of drawing elements.
 - It allows each stroke to be independently managed and altered if necessary, which is critical for functionalities like undo. For instance, if a user wants to undo a recently added color on a specific area, pressing the "undo" button should only affect the last painted section. No other area, regardless of its color or location, should be impacted by this action. Thus, utilizing the path function is essential.
- **Optimized Paint Setup:** The `initPaint` function configures the `Paint` objects with optimizations like `isAntiAlias` and `isDither`. These settings enhance the visual quality of strokes while maintaining performance across various device capabilities.
 - `isAntiAlias` enables smoother edge lines, reducing visual noise without significant performance cost.

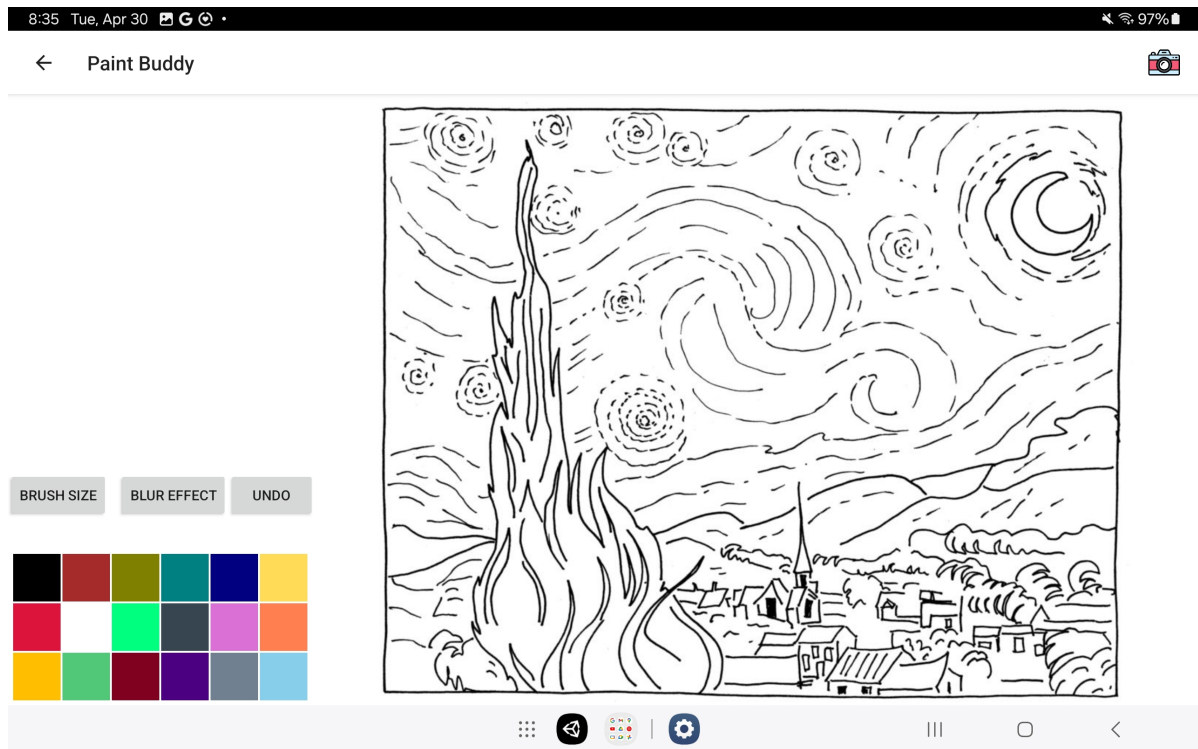


Figure 4.7: Digital canvas of paint application: The Starry Night

- *isDither* helps in handling color gradient renderings better on devices with less color display capabilities.
- **Event Handling and Drawing Efficiency:** In the `onTouchEvent` method, drawing operations are triggered only in response to specific user interactions (`ACTION_DOWN`, `ACTION_MOVE`, `ACTION_UP`), which optimizes the rendering cycle:
 - `ACTION_DOWN` is triggered the moment a user touches the screen. This event marks the beginning of a touch gesture and signifies the start of a new drawing path. The application typically initializes a new `Path` object when this event is triggered. This path will record the coordinates of the user's touch, starting exactly where the touch was first detected.
 - `ACTION_MOVE` is triggered whenever there is a movement across the screen with the touch point still engaged. During `ACTION_MOVE`, the application continuously updates the `Path` with new coordinates following the finger's movement, effectively drawing the line. The continuous update and immediate visual feedback via redrawing allow for a smooth and interactive drawing experience, showing the user their drawing path in real-time.
 - `ACTION_UP` is triggered when the user lifts their finger off the screen, marking the end of a touch gesture. In the applications, it signifies the completion of a drawing stroke. When `ACTION_UP` occurs, the current path is finalized, meaning no further points are added.
- **Save painting progress:** The application utilizes Android's *SharedPreferences* to persistently store the painting data. Each stroke made by the user is serialized into a string format, capturing essential properties like color and stroke width, along with the path's coordinates. This serialized data is saved under a unique key in *SharedPreferences* whenever significant interactions occur, such as application pause (when moving to another application or closing the screen). Upon resuming the application, the painting is seamlessly reloaded from *SharedPreferences*, decoding the serialized string back into drawable paths. This process guarantees that the user can continue their artwork right from where they left off, providing a smooth and user-friendly experience. Moreover, a reset button is provided on the toolbar that clears all colors from the image, allowing a new user to start painting on it again.

5. Data Management and Networking

This aspect of PaintBuddy handles the saving and sharing of painted images, integrating with Android's media store and networking capabilities.

Key operations:

- **Screenshot Functionality:** Captures screenshots of the current state of PaintView, which is used for saving and sharing via socket connection when needed.
- **MediaStore Integration:** Uses ContentValues to properly label and store images within the Android device's gallery.
- **Network Communication via Sockets:** Sends screenshots to the server address connected to the local code for the development of the memory of the robot. This is done to enable the robot to make conversations about the painting. This is implemented using Java's Socket class, making it suitable for real-time transfer of images during the painting session.
- **Use of threads in sending screenshots:** In Android, the UI thread (main thread) is responsible for maintaining smooth user interactions. Network operations, such as sending files to a server, can involve significant delays due to network latency or slow server response times. Performing these operations on the UI thread would block it, leading to a frozen user interface and a poor user experience. By using a separate thread for sending the screenshot, the network operation is offloaded from the UI thread, allowing the application to remain responsive while the screenshot file is being transmitted.
- **Image Compression Before Sending to the Server:** Bitmaps can be very large, especially when capturing full-screen content at high resolutions. Large files take longer to send over a network, consume more bandwidth, and can strain both the sending device's and the receiver's resources. By compressing the image into the PNG format, the file size is significantly reduced without loss of image quality (PNG is a lossless compression format). This makes the transmission more efficient and faster.

Android special permissions used in the application

The application requires specific permissions to ensure proper functionality and user experience.

```
<uses-permission android:name="android.permission.WRITE_EXTERNAL_STORAGE" />
```

This permission allows the application to write the saved screenshots to external storage of the tablet.

Additionally, the permission below is necessary for the application to access the internet, facilitating essential network communications for integrating with the socket connection to pass screenshots to the robot for analysis.

```
<uses-permission android:name="android.permission.INTERNET" />
```

4.5. Personalization of conversation

The personalization of the conversation was done in the following two ways:

- The user's name is asked at the beginning so the robot can use it during the conversation. This personalizes the interaction, making the user feel that the robot is speaking directly to them, rather than having a generic conversation.
- The user was asked which painting they were doing: easy, medium, or difficult. The paintings are based on Vincent van Gogh's famous works. Each difficulty level corresponds to a specific painting: easy is "Bedroom in Arles," medium is "Sunflowers," and difficult is "The Starry Night." When the user mentions their chosen difficulty level, the respective painting is mapped to it and fed to the LLM. This ensures the LLM knows which painting the user is working on at all times. Consequently, the LLM can provide more relevant suggestions or comments on the painting,

rather than making random remarks. This approach helps the user feel more connected to the robot, as the robot's feedback is specific to their activity. Additionally, the robot can use knowledge about the painting's details, techniques, and history to enhance the conversation, further enriching the user's experience and engagement.

4.6. Fail-safe Methods

Sometimes the language model takes a long time to generate a response, especially when retrieving high-ranked memory or analyzing differences between images in multimodal scenarios. In such cases, the robot uses response fillers like "I understand," "Oh! That sounds amazing," and "Okay, let me think about it." These statements are spoken by the robot using Wizard of Oz functionality, where predefined fillers are sent out if the robot seems to take time during its response generation, as mentioned in section 4.3.6. Statements like these provide the robot with extra time to create responses generated by our response generation mechanism.

5

Results

During the analysis of the data obtained from our research study, three broad categories were observed among the participants. These categories are self-defined and do not follow any established classifications from previous studies.

1. **Category 1: Participants who like to paint (C1):** There were 4 out of 8 participants who fall in this category. (Participant1 (P1), Participant2 (P2), Participant4 (P4), Participant7 (P7))
2. **Category 2: Participants who don't like to paint but are open to trying it (C2):** There were 3 participants in this category (Participant3 (P3), Participant5 (P5), Participant6 (P6))
3. **Category 3: Participants who dislike painting and are not open to trying it (C3):** There was only one participant in this category. (Participant8 (P8))

5.1. RQ1 result

Restating RQ1:

How does incorporating episodic memory and visual short-term memory in a social robot affect the following aspects during interactions with older adults?

- **Engagement in conversation**
- **Sense of companionship**
- **Valence of emotional state**

5.1.1. Analysis of "Engagement in conversation"

As mentioned in Section 3.8, engagement in conversation was studied by analyzing the conversations of the participants with the robot. We focused on participants' response latency, turn-taking behavior, response types, and their level of friendliness during the conversation. The following is the result for each category:

C1: Participants who like to paint

Response Latency: Participants in this category responded promptly throughout the interactions, maintaining a fluid and natural conversation flow. There were no significant delays in their responses. For instance, when the robot asked P7 about their painting process, they immediately responded with:

"I'm going right now with a large brush, it's quicker
and easier to paint and maybe I can finish quickly."

Turn Taking: The participants demonstrated effective turn-taking throughout the interactions. They not only answered the robot's questions but also asked their own and initiated topics for conversation, contributing to a dynamic and reciprocal conversation. P2, for instance, shared about the Sunflower painting:

"It is a very famous painting, it is lovely and it shows the sunshine in the country and that's lovely to see after winter"

This shows an effort to engage the robot in a two-way dialogue. However, there were times when the robot needed to make additional efforts to engage this participant (P2) in conversation by commenting on their painting progress and asking more questions. This could be likely due to their focused attention on painting and providing detailed explanations about their artwork.

Response Type: Responses from participants were detailed and went beyond one-word answers, often including personal thoughts and feelings. For instance, when a participant (P1) previously joked about adding spaceships to their painting, they further shared:

"No, I am not adding spaceship, I was joking"

This adds depth to the interaction and indicates that participants were actively engaged and invested in the conversation. However, on certain occasions, one participant (P2) responded with short replies and spoke less to the robot.

Friendliness: The participants exhibited friendliness and warmth towards the robot. They appreciated the robot's compliments and suggestions, which contributed to a positive interaction atmosphere. For example, when the robot asked P4 if they liked painting, they responded with:

"Oh well, yeah, I do, but I don't have much time.
And how are you?"

This shows a friendly attitude and an attempt to connect with the robot.

C2: Participants who don't like to paint but are open to trying it

Response Latency: Participants consistently responded promptly to the robot without noticeable delay. This promptness was observed across all three participants, suggesting they were attentive and ready to interact.

Turn Taking: There were mixed results in turn-taking. For instance, while some interactions showed a fluid conversation, others revealed that the robot had to prompt multiple times before receiving a response. For example, P5 sometimes followed a pattern where the robot had to say more than once before getting a reply, indicating that the robot was making more effort to keep the conversation going. However the other two participants responded to the robot's questions, asked their own, and engaged in general conversation. For example, P3 continued the discussion by sharing their feelings about Van Gogh's use of bright colors, stating:

"Yellow, the color of the flower, is also the color of the sun, while green leaves mean the beginning of summer."

Response Type: While participants occasionally responded with short phrases such as "yes," "no," "thank you," and "I don't know," they also provided more detailed responses at times. For instance, P5 shared their feelings about painting *The Starry Night* by saying:

"Oh dear, I feel like an artist"

P3 elaborated on their painting experience by discussing the emotional impact of colors:

"The colors speak to me, they are bright, its so imaginative."

This mix of short and detailed responses indicates moderate engagement in response type, with room for improvement in eliciting more consistently detailed communication.

Friendliness: Participants demonstrated friendliness and warmth towards the robot throughout the interactions. For instance, P6 maintained a polite and cooperative tone, even though they expressed a lack of personal interest in painting. P3 expressed gratitude and friendliness by saying, "thank you for the compliment." P5 also showed appreciation, saying, "thank you," in response to the robot's positive feedback. This consistent display of friendliness suggests a positive interaction atmosphere.

C3: Participants who dislike painting and are not open to trying it

Response Latency: The single participant in this category, P8 responded promptly to the robot with some delay at times.

Turn Taking: The turn-taking between P8 and the robot was generally poor, with the participant responding briefly to the robot's questions but not actively asking questions or engaging in conversation with the robot. Moreover, at times they would also not reply to the robot with relevant answers because they did not focus on what the robot was saying. However, P8 expressed a lack of interest in painting early in the conversation, which affected the overall engagement. For example, when asked about their feelings towards the painting, P8 responded with reluctance to engage deeply with the activity by saying :

"I wouldn't be painting if I didn't have to"

Response Type: P8's responses were often brief and conveyed minimal detail. Many answers were short phrases such as "no not at all," and "no, I would like to go outside," This indicates a low level of engagement in providing detailed responses. The participant did not elaborate on their feelings or experiences significantly, which suggests that the robot's memory capabilities did not succeed in eliciting more in-depth communication in this instance.

Friendliness: P8 exhibited a lack of friendliness and enthusiasm towards the interaction. They expressed clear disinterest in painting and the activity, as seen in responses like:

"I just don't like painting. I like to go outside or listen to music."

The participant was also unable to take the robot seriously and did not listen to it at times. Their tone was generally negative, and there was no display of warmth or positive emotions towards the robot.

Final summary on "Engagement in conversation"

The incorporation of episodic memory and visual short-term memory generally had a positive impact on participants in Category C1. They responded promptly to the robot without any delay, along with effective turn-taking and detailed responses. However, the robot had to make a specific effort to engage one participant (P2) in conversation.

Participants in Category C2 responded promptly, showing low response latency. Furthermore, there were varied results in terms of turn-taking and response types. While some participants in this category provided detailed responses, others responded with brief answers such as "yes" or "no" to some of the robot's questions. In one instance, the robot had to repeat itself multiple times to elicit a response from a participant.

The single participant in Category C3 demonstrated higher response latency as compared to participants in C1 and C2. They also preferred not to engage much in conversation and gave short responses to the robot's questions and did not initiate any other topics.

Overall, all participants in C1 and C2 interacted with the robot in a friendly manner, greeting it pleasantly and maintaining a pleasant tone throughout their interactions. However, the tone of the single participant from C3 was not warm or friendly towards the robot. They often smirked when the robot attempted to converse, indicating a lack of seriousness.

5.1.2. Analysis of "Sense of companionship"

As discussed in Section 3.8, sense of companionship was analyzed using the responses of participants in the interview. The analysis for each category is provided below.

C1: Participants who like to paint

Participants in this category had mixed feelings about the sense of companionship provided by the robot. While two participants felt a sense of company, one participant found it challenging to perceive the robot as a companion due to its non-human nature, stating:

"It's difficult to say. Yes there was something looking at me while I was painting, but it isn't a human. You see no living being before you. Since it's a machine, it makes it difficult to see more humane characters in it."

Another participant had a different opinion about the robot's features. They noted that the robot was able to keep them engaged, specifically stating its human-like characteristics:

"Robot is especially keeping busy in a conversation. The voice is agreeable to your ears. It is very human like. So it is not disturbing - it is natural."

Regarding the robot's responsiveness, three participants felt being understood by the robot, although 2 participants noted that the robot was somewhat slow in responding, with one participant, finding the delay disruptive to their engagement.

C2: Category 2: Participants who don't like to paint but are open to trying it

Two participants in this category generally felt alone despite the robot's presence, with one of them mentioning:

"Yes I felt alone, but the robot was talking to me"

One participant acknowledged the robot's help in attempting to provide companionship, mentioning that they had no issue with talking to the robot. Additionally, all three participants felt understood and listened to by the robot.

C3: Participants who dislike painting and are not open to trying it

Participant in this category did not feel a sense of companionship with the robot. Despite this, the participant acknowledged that the robot understood and responded to their inputs appropriately, indicating that while the robot's communication was effective, it did not translate into a sense of companionship for those disinterested in the activity.

Final summary on "Sense of companionship"

Varied effects on the sense of companionship were felt by older adults during interactions. Participants in all the categories had mixed feelings about the robot as a companion. While some participants felt a sense of companionship and found the interaction enjoyable, some felt that the robot did not provide them with companionship. One participant struggled to view the robot as a companion due to its non-human nature. In contrast, another participant felt the robot was more human-like, particularly because of its natural-sounding voice. Nonetheless, most participants acknowledged that the robot understood them and they felt listened to by the robot. The robot responded effectively, although some noted delays in responses. Overall, while the robot's communication abilities were generally effective, it had mixed results in providing a sense of companionship to all the participants.

5.1.3. Analysis of "Valence of emotional state"

As previously mentioned in Section 3.8, valence of emotional state was measured using the responses of participants from the interview. The analysis for each category is provided below.

C1: Participants who like to paint

Participants in this category generally felt that the robot reacted to their emotions. Three participants acknowledged the robot's efforts to connect with their emotions, with one of them specifically noting the importance of understanding emotions in a conversation:

"When I explained that I was fond of going to museums, I think it understood my emotions for that. I think its very important that the other person understands your interests."

Another participant acknowledged the robot's attempt to try to understand them more by asking questions, stating:

"Can never relate exactly to someone you don't know at all - it was trying to understand you and asking questions to try to come into your world."

One participant was unsure if they themselves displayed any emotions. None of the participants reported feeling frustrated by the robot's actions or responses. During the interaction, participants' moods ranged from neutral to relaxed and comfortable, with one of them stating how the presence of the robot altered their mood:

"I think it changes, I got more relaxed. At first I didn't know what to expect."

One participant felt particularly at ease, noting the natural and conversational nature of the interaction. After the interaction, two of the participants felt better or relaxed, while two participants felt the same. One participant highlighted that the robot's attentiveness and non-nagging behavior made the interaction feel like a supportive discussion, potentially beneficial for PwD:

"I was entertained and it was a nice conversation. Robot left the freedom to react in my way. Felt like a discussion, and not like someone who nagged you. This felt like someone who was present and gave you attention and interest."

This also indicates that the participant felt autonomous in their decisions and did not feel compelled to act according to the robot.

C2: Category 2: Participants who don't like to paint but are open to trying it

Participants in this category had mixed experiences with the robot's emotional reactions. Two participants felt that the robot connected with their emotions and reacted to them, stating:

"The robot is connecting with my emotions"

However, one did not notice any emotional response from the robot. None of the participants felt frustrated by the robot's actions or responses. Mood changes during the interaction were mostly neutral, though one participant experienced joy. After the interaction, all the participants who had neutral emotions during the interaction felt better. One even made a light-hearted joke about the future of their painting. The robot's interaction thus affected their emotional state positively or neutrally, with no negative reactions.

C3: Participants who dislike painting and are not open to trying it

The single participant in this category felt that the robot reacted to their emotions, particularly appreciating the robot's acknowledgment of the potential frustrations of painting. This participant did not experience any frustration during the interaction. Their mood remained largely unchanged throughout and after the interaction, indicating that while the robot's attempts to connect emotionally were noted, they did not significantly affect the participant's overall mood.

Final summary on "Valence of emotional state"

Figure 5.1 shows the number of participants in each category and their perceptions of the valence of emotion provided by the robot.

Three out of four participants in Category C1, who enjoy painting, felt that the robot responded to their emotions, resulting in them feeling more relaxed and comfortable. One participant even highlighted the potential benefits for PwD, appreciating the robot's supportive and non-nagging nature. Participants in Category C2 had mixed feelings about the robot's emotional connection, with two feeling understood by the robot. In contrast, the single participant in Category C3 acknowledged the robot's emotional reactions but did not experience a significant mood change.

However, according to Figure 5.1, among participants in Category C2, two felt neutral and one felt positive or joyful during the interaction. Surprisingly, all of them reported a positive mood after the

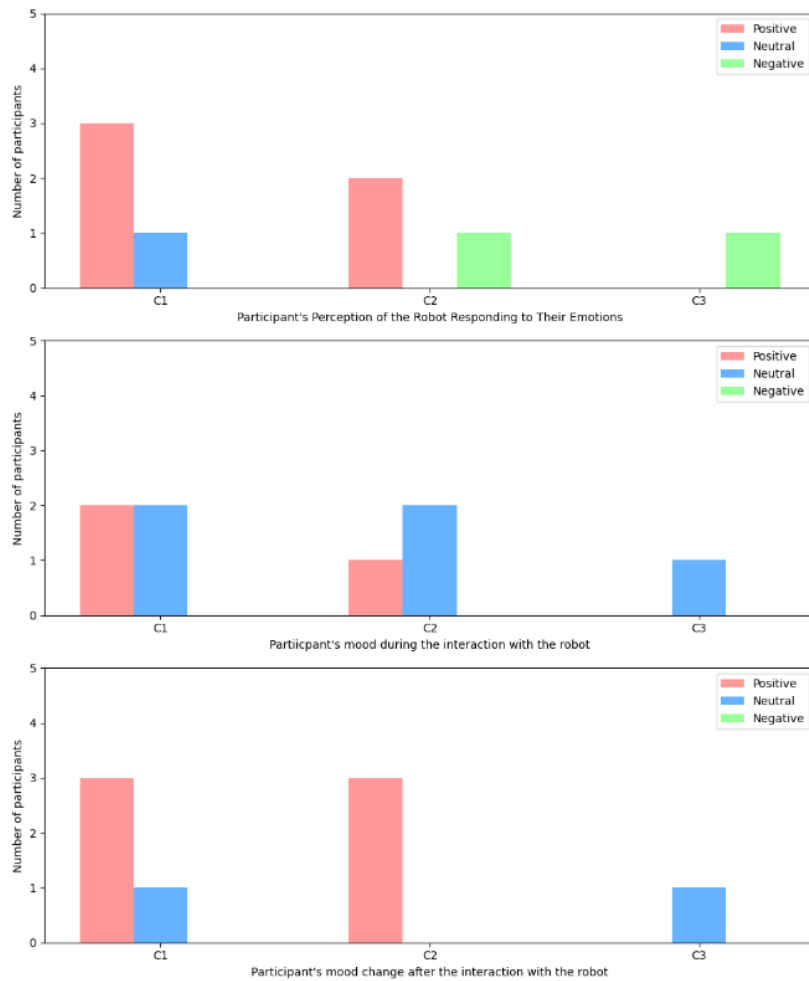


Figure 5.1: Sense of perceived valence of emotion by category

interaction, indicating that the activity had a beneficial impact on improving their mood. Similarly, in Category C1, two participants felt neutral and two were in a good mood during the experiment. Afterward, three participants experienced a positive mood change while one remained neutral. However, due to the limited data available, we cannot definitively conclude whether the activity directly caused these mood changes. Moreover, all the participants mentioned that the robot did not frustrate them at any point.

5.2. RQ2 result

Restating RQ2:

How does introducing an art activity program facilitated by a social robot affect the engagement levels of older adults in the activity?

As mentioned in Section 3.8, this research question is investigated by analyzing a series of screenshots from the participants' paintings and their responses during the interview.

5.2.1. Analysis of interview responses

C1: Participants who like to paint

All the four participants enjoyed painting with the robot and appreciated its guidance and interaction. However, one participant found the robot's responses slow, which was a drawback. Overall, the robot's presence was positively received and added value to the painting experience. One participant noted

that the robot's discussions helped maintain their thoughts and imagination on the painting, stating:

"I enjoyed painting with the robot. It guided me and kept me busy at a certain point, made my thoughts about painting more clear and made me think about what my plans could be and what I could do during the painting."

Moreover, three participants mentioned that they spent longer painting with the robot and would have painted less otherwise, with one of them noting a very important aspect of painting with the robot:

"I would have painted less longer if Milo wasn't here. He keeps you busy with the discussion about painting so your thoughts and imagination and focus is on the painting because he talks about it."

However, one participant mentioned that they would have painted the same amount regardless of the presence of the robot. One participant noted that while they would have painted alone, the robot could help alleviate loneliness for others.

Three participants expressed that painting with the robot was a different experience compared to painting without it. They felt that the robot's suggestions and its presence helped them consider new aspects of painting, such as creating depth, ultimately enhancing their artwork. One aspect appreciated by all participants in this category is the robot's suggestions with one of them describing how the robot improved their artwork:

"He pointed out how to create depths by using the background, and I had not thought of that before. It gives the painting more depth indeed."

They found these suggestions highly useful during their interactions. However, one participant noted that the suggestions could sometimes feel overwhelming, mentioning:

"Sometimes the suggestions were a lot - I would rather do it myself but then you can ignore what the computer is saying (you won't be punished for it or something). Yeah. Not only for myself, but for the group it is meant to be, it will be great help."

Interestingly, this participant suggested that this feature could be particularly beneficial for PwD, as it assists them in making decisions.

In this group, most participants partially accepted the robot's suggestions. Additionally, all 4 participants felt that the robot engaged in meaningful conversation with them, noting that the robot referred to previously discussed elements in the conversation. Regarding the impact on their painting activity, 2 out of 4 individuals expressed that the robot sparked their interest in painting. However, 2 others did not find the robot useful in making the activity more engaging for them.

Furthermore, 3 out of 4 participants reported that the robot motivated them to paint. One participant mentioned that the robot kept them occupied and helped them develop a clearer plan of what they wanted to paint, thereby enhancing their overall painting experience.

C2: Category 2: Participants who don't like to paint but are open to trying it

Among the three participants, two found painting with the robot fun and interesting, with one of them mentioning:

"It was interesting to communicate with Milo. I enjoyed it."

One participant felt it didn't make much difference to them personally, where they stated:

"I know it is the future to do something like this, but for me personally it did not make difference to do it with the robot. He tries to get my choices for all the colors. But I am painting and he isn't"

The novelty of the interaction was noted, but it did not significantly enhance their painting experience. Two participants felt that the robot did not affect the duration of their painting, indicating they would not have painted longer with or without the robot. However, one of them stated that they would not have painted at all without the robot.

Additionally, all three participants felt that their painting would not have changed much without the robot, believing they would have painted the same way. This indicates that the robot's presence did not significantly alter their approach or feelings towards the painting process. Furthermore, two participants in C2, similar to those in C1, also found the robot's suggestions to be the most important and helpful feature. One participant highlighted that the robot had the ability to make them enthusiastic about painting.

Participants in this category were less influenced by the robot's suggestions, with one of them indicating:

"Most of the time I rejected because I want to make my own choice. But I don't mind that he made suggestions."

Therefore, the participants often preferred to make their own choices. They recognized the robot's efforts to relate comments to their painting, noting its ability to reference their work and interests when they discussed:

"Mostly it had a reference with the painting but it asks about the interest of the painting. If I choose a color he knows which color I use. The robot knew what I was painting."

The novelty of the robot's presence made the activity more interesting for all 3 participants in this category, and they saw potential for its usefulness in the future, especially for individuals who might feel lonely. The robot motivated 2 out of 3 participants, its interaction and conversation provided a new and engaging experience, sparking interest in an activity these participants would not usually do.

C3: Participants who dislike painting

The single participant did not enjoy painting with the robot and would have preferred to engage in other activities like going outside. They noted that the robot's presence was the sole reason for their participation in the activity, indicating that they would not have engaged in painting at all without it. One of the most helpful features mentioned by the participant was the suggestions provided by the robot. However, the robot was not successful in changing the participant's experience. They felt that no one, robot or human, could make them enjoy painting.

Participants in this category did not find the robot's suggestions influential and felt that its comments were not specifically relevant to their work and they did not listen carefully to the robot, mentioning:

"It might have been talking about any painting in my opinion not specifically this one but maybe it's my lack of knowledge, I don't know paintings"

The presence of the robot did not enhance their interest in painting, as they were not inclined to enjoy the activity regardless of the any assistance. Consequently, the robot did not motivate them to continue painting. They demonstrated a clear disinterest in painting, and the robot's capabilities did not alter their engagement or enthusiasm in any way.

5.2.2. Analysis of paintings

The analysis of all the screenshots of the artworks for each participant was conducted, and the results are presented below.

C1: Participants who like to paint

Participants in this category demonstrated high engagement levels throughout the painting activity. They actively used all the tools available on the tablet, including various brush sizes and the blur effect, and showed creativity and precision in their work. Each screenshot taken every 45 seconds revealed

continuous progress, indicating sustained engagement. These participants were innovative, often experimenting with colors and adding personal touches to their paintings. They completed their sessions with detailed and vibrant artworks.

C2: Category 2: Participants who don't like to paint but are open to trying it

Participants in this category also showed high engagement levels, though with some variation in precision and approach. They used a variety of tools and colors, and their painting progressed steadily as evidenced by the screenshots taken every 45 seconds. 2 participants demonstrated consistent activity, even though one of them had a very scattered approach where they randomly painted things. Another participant painted hastily but still engaged creatively with the task, actively using different brush sizes and the blur effect. Despite not usually painting, these participants were engaged throughout the session.

C3: Participants who dislike painting

The single participant in this category showed minimal engagement. They used a limited number of colors and made only slight progress between screenshots as compared to other participants. Their painting activity was minimal, and they did not fully utilize the tools available on the tablet.

5.2.3. Final summary on RQ2

Introducing an art activity program facilitated by a social robot had varying effects on the engagement levels of older adults, depending on their initial interest in painting. In C1, the majority appreciated the robot's guidance and interaction, finding it beneficial to their painting experience. In C2, opinions were mixed, with some finding the interaction fun and interesting, while others felt indifferent. In C3, the only participant did not enjoy painting with the robot, preferring alternative activities.

In C1, most participants acknowledged that the robot contributed to longer painting sessions, with the majority also noting improvements in their painting skills with its assistance. Conversely, participants in C2 and C3 perceived no impact on their painting duration or improvement from the robot.

Overall, participants across C1, C2, and C3 generally valued the robot's suggestions as a beneficial aspect of their painting experience. In C1, all four participants and two participants in C2 highlighted this feature as particularly helpful. Additionally, one participant in C2 appreciated the robot's role in fostering enthusiasm for painting. Even in C3, where the participant's overall enjoyment was lower, the robot's suggestions were still noted as the most helpful aspect. Moreover, Participants in C1 showed a mixed acceptance of the robot's suggestions, while participants in C2 and C3 did not accept the robot's suggestions.

Participants in C1 and C2 generally appreciated the robot's ability to engage in meaningful conversations related to their painting, while participants in C3 felt that the robot's comments were not relevant to their work. Participants' responses to the robot's impact on sparking interest and motivation in painting varied significantly across the three categories. In C1, while some found the robot sparked their interest and motivated them to paint, others did not perceive it as useful in enhancing their engagement. In C2, the novelty of the robot's presence made the activity more interesting for all participants, and it effectively motivated most of them through interactive engagement. Conversely, the participant in C3 remained uninterested in painting, unaffected by the robot's presence or capabilities.

The analysis of the screenshots taken every 45 seconds shows that the social robot effectively facilitated engagement in the painting activity for older adults in Categories C1 and C2. Participants in these categories demonstrated continuous progress, creativity, and active use of the tools provided. However, the robot was not effective in engaging participants who have a strong disinterest in painting and are unwilling to try (C3). These findings suggest that while the social robot can enhance engagement for most participants, it may not significantly impact those who are inherently disengaged from the activity. The differences in the paintings among the 3 categories can be seen in Figures B.1, B.2, and B.3. Each painting is the final result of their art session.

5.3. Results on Memory of the robot

Participants were also asked specific questions during the interview to assess the robot's episodic memory and short-term memory, as discussed in Section 3.8. The following are the results of this assessment.

5.3.1. Episodic memory

Seven participants felt that the robot remembered aspects of their conversation, noting that it could recall details about their painting, such as colors and parts they were working on. However, two participants mentioned that the robot had some delays in responding, but it did not concern them:

"It took some time for him to understand what I said and respond to it. This did not bother me."

Moreover, one participant expressed fear about the future implications of robots having such memory capabilities when they discussed:

"Yes. I am a little bit scared in the future. Are robots going to take over or not?"

Six participants felt positive or neutral about the robot's memory, with responses ranging from "good" to "funny" and "okay." One participant, however, felt scared about the implications of robots having memory as mentioned before.

Seven participants felt that the robot's ability to remember improved their interaction, making the conversation smoother and more engaging, with one of them specifically noting the typical nature of conversation:

"It was a typical conversation, question and answer or a normal conversation."

Six participants felt that the robot's memory made the conversation more personal. One participant felt neutral about maintaining privacy. In contrast, another participant mentioned privacy concerns, noting that complete personalization is subjective and people might react differently to it, mentioning:

"We also don't want it to invade my privacy, so that's good. However, how people react to it is very subjective. I didn't find it disturbing or strange, but individuals without context might struggle with the machine."

However, one participant was unsure if the robot remembered things from their conversation, as they were not paying much attention. They also had specific expectations from the robot regarding tracking their painting progress and making suggestions:

"It didn't make any remarks about coloring outside the lines."

They felt indifferent about the robot's memory, stating it was okay for the robot to have memory and that without it, the interaction would be bad, implying that the memory feature was beneficial even if they did not engage deeply with it. The participant acknowledged that the memory feature made the robot less mechanical, but they still felt aware that they were talking to a machine.

To summarize, incorporating episodic memory in a social robot generally had slight positive impact on participant's painting experience during the painting activity. Seven out of eight participants noticed and appreciated the robot's memory capabilities, which improved conversation quality and made interactions feel more personal. One participant expressed fear about the future implications of robots with memory. The single participant in Category C3 found the memory feature beneficial for more human-like interaction quality, though they could not take the robot seriously as felt they were talking to a machine.

Effectiveness of Episodic memory

We further analyzed the conversation dataset to determine if the robot effectively utilized the memories it formed during the conversation. The following are the results of this analysis:

The robot's use of a memory model in the painting activity proved effective in eliciting detailed and engaged responses from participants in Categories C1 and C2. However, the session with one participant in Category C3 was so short that the robot could not utilize its memory model effectively. By recalling specific memories and asking contextually relevant questions, the robot not only maintained a coherent dialogue but also enhanced the overall interaction for most of the participants. This approach allowed participants to delve deeper into their experiences and thoughts, enriching the painting activity.

One such instance occurred when a participant had a conversation about having painters in the family:

Participant: I have painters in the family but it's not for me,
I have my niece she paints portraits, landscapes,
most art

Robot: Could you please tell me which genre of art you enjoy
painting most?

Participant: space, nebulas or coasts, horizon.

The robot later recalled the participant's highest-ranked memory and asked for more information by posing another question based on that memory. This personalized inquiry led the participant to reveal specific genres they were interested in. The robot's ability to remember and reference this detail encouraged the participant to reflect on and articulate their artistic preferences more clearly, demonstrating the value of personalized interaction.

Another notable interaction happened when a participant discussed their progress on the painting, stating:

Participant: I haven't started with the green color yet,
I'm just starting now.

Robot: What kind of green are you planning to use for
the cypress tree?

Participant: Well, I need to add blue because cypress is not
really always green or dark. And I've put some gray
in it, that is too dark. So I'll take some yellow.

This detailed response demonstrates the robot's effectiveness in encouraging the participant to articulate their artistic decisions and techniques, thereby enhancing their engagement with the painting process. These interactions highlight how the robot's use of memory can significantly enrich the participants' experience by encouraging deeper reflection and discussion about their artistic choices. Some other notable interactions have been mentioned in Table A.5.

Despite a great positive impact of the robot's memory capabilities, there were instances where the use of episodic memory did not enhance engagement. For example, when a participant expressed their emotions about paintings:

Robot: That's the spirit! Painting is all about
experimentation and finding your own unique style.

Participant: yes, it's also therapeutic and calming for me

Robot: Is there a particular memory or feeling that
you associate with painting that brings you
therapeutic and calming effects?

Participant: I don't know, not really

This that the robot's attempt to build on past interactions did not lead to deeper engagement. It is also evident that while the robot's memory can help personalize interactions, sometimes the follow-up questions can be difficult for participants, potentially failing to stimulate cognitive functioning and engagement.

Overall, the robot's use of episodic memory to recall and rank certain memories, then ask tailored questions, impacted participants' responses in most cases. By encouraging them to provide more specific, detailed, and emotionally rich answers, the robot had a positive impact on the older adults in the painting activity. This approach allowed participants to explore and express their creativity and emotions more fully, enhancing the overall experience. However, in some instances, the questions posed by the robot were a bit difficult for the participants to answer, which led to them not providing more details in the conversation.

However, the use of episodic memory for participants in Category C3 was not feasible due to the short duration of the painting activity. This underscores a limitation: the robot can only effectively utilize episodic memories after it has built up a sufficient amount from ongoing conversations. The robot relies on these previous interactions to enhance engagement and maintain continuity in conversation. Without enough memories to reference, the robot cannot effectively build upon past interactions or personalize its responses.

5.3.2. Short term memory

Six out of eight participants felt that the robot understood what they were painting. They noted that the robot's suggestions and comments were relevant to their work, with most of them stating comments like:

"I felt that he knew, based on his suggestions."
 "Which part of painting I was working on and the colours."

However, one participant felt that the robot misinterpreted their painting where they mentioned:

"Sometimes I had an idea but I did not know whether the robot understood my idea. I thought the thing I was painting was fire, but the robot said it was a tree."

Here, the robot's understanding did not align with the participant's interpretation of the painting. The robot recognized that they were painting "The Starry Night" and referred to the tree in the painting as a cypress tree. However, the participant believed they were painting fire, as they were unaware of the tree in the painting. This contradiction in thought processes can lead to conflicting arguments.

Seven out of eight participants felt that the robot made relevant suggestions regarding their painting. While some suggestions were not always utilized, participants appreciated the guidance provided. One participant highlighted their preference for suggestions, stating:

"Yes I preferred it making suggestions"

One participant, however, sometimes found the suggestions redundant because they had already completed the task.

Six out of eight participants felt that the robot's awareness of their painting progress improved their conversation and made the interaction more engaging, as they confirmed when asked about the robot's awareness of their painting progress:

"Yes, it did, it improved the conversation"
 "If I choose a color he knows which color I use."
 The robot knew what I was painting."

However, one participant felt that the robot repeated suggestions about tasks they had already completed, indicating a lack of real-time awareness. They stated:

"No, he kept saying about the blue wall and the floor.
He talked about using a color but I already did that."

This suggests that in this particular situation, the robot failed to analyze the short-term memory and thus provided irrelevant comments at times.

Another participant, P8, did not feel that the robot was aware of what they were painting. However, they also admitted to not paying much attention to its comments, mentioning:

"It didn't didn't refer to anything within the
painting or anything that I was doing. I didn't have
that feeling. I missed as I didn't listen carefully
to the robot"

Furthermore, they did not recall the robot being aware of their painting progress, suggesting a disconnect between the robot's feedback and their actions.

To summarize, giving visual short-term memory to a social robot generally had a positive impact on older adults participating in a painting activity. 6 out of 8 participants felt that the robot understood their work and made relevant suggestions, enhancing their experience. They appreciated the robot's awareness of their progress, which improved conversations and made the activity more engaging. However, one participant highlighted issues with real-time awareness, as the robot provided details about paintings that the participant had not worked on. In contrast, the one participant in Category C3 did not feel that the robot effectively recognized their actions or provided relevant suggestions, reflecting a lack of engagement.

Effectiveness of Short term memory

We conducted an in-depth analysis of the conversation dataset to evaluate whether the robot effectively utilized the short-term memories it formed from receiving screenshots on the tablet. Here are the findings from this analysis.

The robot's ability to observe and comment on the immediate changes in the paintings helped to provide real-time feedback and encouragement, enhancing the painting experience. There were several occasions where the social robot effectively boosted participants' engagement through recognition and praise of their progress. For example, in the instance below:

Robot: Wow, you've added some fiery reds and yellows to
the cypress tree, it's really starting to stand
out against the night sky!
Participant: yes, maybe I am also a painter.

This indicates that the robot's acknowledgment and praise significantly boosted the participant's confidence, making them feel more capable and artistic. Such positive reinforcement encouraged participants to view themselves in a more positive light, enhancing their overall engagement with the painting activity.

In another instance:

Robot: Wow, you've added a beautiful swathe of dark green
to the cypress tree! It's really starting to come alive.
Participant: It's not a masterpiece, but thank you. You
are really flattering.

This exchange reveals that while the participant received the positive feedback with humility, they also felt encouraged and valued by the robot's praise. These interactions underscore how the robot's recognition and supportive comments fostered a more engaging and motivating environment for the participants.

One noticeable moment occurred when the robot misinterpreted the colors:

Robot: Wow, you've started coloring the floorboards yellow!
That's looking fantastic.
Participant: not its not yellow
Robot: Oh, I apologize! It looked yellow in the image.
Could you tell me what color you are using for the
floorboards? Perhaps a shade of brown?
Participant: not its not yellow, its gray
Robot: Ah, I see! Gray is an excellent choice for the
floorboards. It will create a neutral base for the other
colors in the room and add a sense of depth and realism.
I'm excited to see how it looks as you continue painting!

It has been observed that the robot quickly apologized for its misunderstanding and asked the participant for clarification. This highlights an important aspect in human-robot interaction, where the robot's ability to acknowledge and correct errors can create clearer communication.

Throughout the painting session, there were various instances where participants acknowledged the robot's understanding of their progress. When the robot made comments like:

Robot: Wow, you've started adding color to the chair!
I love how you're bringing Van Gogh's masterpiece
to life.
Participant: Well, thank you

These interactions demonstrated an appreciation for the robot's observations but did not lead to deeper engagement or dialogue.

On several occasions, participants did not reply to the robot's comments at all. For instance:

Robot: Wow, you've added some details to the houses in
the town! It's looking really good

In certain cases, these comments based on robot's visual short term memory were met with silence. While the robot's remarks acknowledged the participants' progress and added a layer of interaction, the minimal verbal feedback might also be due to the participants' focus on their painting.

Overall, the short-term memory model was effective in providing immediate, relevant feedback that was seen as positive by most of the participants. By observing and commenting on the differences in the paintings, the robot was able to offer real-time encouragement and specific praise, which helped most of the participants feel more confident, proud, and connected to their artistic process. This approach not only created a positive and enjoyable painting experience but also encouraged participants to think critically and reflect on their progress, leading to a deeper and more meaningful involvement with the activity.

5.4. Assessment of Dialogue Adherence to Guidelines for Conversations with PwD

Based on the guidelines outlined in Section 3.1, conversation strategies were designed as detailed in Section 4.2.3. Consequently, we conducted a further analysis of the conversation database to determine whether the robot adhered to the conversation guidelines.

5.4.1. Clarification

Episodic memory was used to clarify or gather more information from participants about their thoughts and ideas. The robot successfully asked questions that encouraged participants to provide more details. For instance, in the conversation below:

Participant: I like the Van Gogh paintings because there
are bright colors and summer is beginning.

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Robot: Can you share what you like most about Van Gogh's use of bright colors in relation to the summer season?

Participant: Yellow, the color of the flower, is also the color of the sun, while green leaves mean the beginning of summer.

Here, the robot successfully asked the participant a question to clarify their perception of Van Gogh's paintings. However, the robot did not always succeed in obtaining clarifications for answers from the participants. There were some instances when the robot posed difficult questions, which led to the participants not providing detailed answers. This issue has been previously discussed in Section 5.3.1 under the effectiveness of the robot's episodic memory.

5.4.2. Exploration

Exploration was primarily conducted using predefined questions; however, the robot also asked additional questions to gain deeper insights into the person's interests and views. Given below is an example of such occurrence:

Participant: I sometimes go to museums but only with my sister because she likes it, and I enjoy doing something with the family

Robot: Do you have a favorite museum you visit together?

Participant: We went to Amsterdam do you know the museum?

Eventually, the participant recalled the museum's name. In similar ways, the robot was successful in getting the participant's views and interests.

5.4.3. Moderation

The robot was able to introduce topics and maintain general conversations as it was programmed to always stay focused on art-related subjects. For example, in the conversation below, the robot initiated a topic for discussion with the participant:

Robot: Do you have any personal memories related to this painting?

Participant: No personal memories, it's just beautiful. I saw a lot of paintings in museums in Gelderland, and I loved it then.

In addition to predefined questions, the robot could continue the conversation in various instances. For example, when a participant joked about adding spaceship to Van Gogh's painting, they further said:

Participant: But there is no spaceship in Van Gogh's painting

Robot: That's the beauty of art! You can always take inspiration from existing masterpieces and reinterpret them in your own way.

Moreover, since the robot was instructed to stay only on painting-related topics, it responded to a participant who did not enjoy painting and was replying in short sentences by shifting the conversation. The conversation unfolded as follows:

Robot: Do you have any questions about painting or Van Gogh's techniques?

Participant: No

Based on the participant's response, it became evident that the conversation process could be improved for participants who dislike painting to provide a better experience with the robot.

5.4.4. Providing clear and simple message

The robot generally provided clear messages, but in many instances, its responses were too lengthy, which is not ideal for PwD. For example, when asked for suggestions on painting villages, the robot replied with:

```
That's a great question! Since you like to add a personal touch to your work, let's explore incorporating elements of a village into a painting inspired by Van Gogh's 'Starry Night' style. How about depicting a small village nestled amidst rolling hills, with quaint houses illuminated by warm lights against the vibrant night sky? We could include a winding path leading towards the village, inviting viewers to explore this magical world. What do you think?
```

Such lengthy responses can be challenging for PwD to follow. Although the LLM used for the robot's speech was instructed to provide concise responses of maximum two sentences, there were instances where longer responses occurred. Improvement is needed to ensure that responses are kept brief and clear to facilitate better engagement in conversations with PwD.

5.4.5. Validation

The robot successfully validated the responses of participants during general conversations every time. The conversation below serves as an example of this:

```
Participant: Yes, maybe I am also a painter
Robot: That's the spirit! Painting is all about experimentation and finding your own unique style.
```

Furthermore, the robot was able to track the painting progress using short-term memory and acknowledged the participant's progress by saying sentences like:

```
Wow, the swirling sky is looking amazing with those extra touches of blue and yellow!
```

5.4.6. Rescue

The robot provided help and support whenever participants faced difficulties. For instance, in the conversation below:

```
Participant: I think it's very beautiful and it's a challenge to paint it
Robot: It's wonderful that you find the painting beautiful and challenging. It's quite a masterpiece! The dark blue is looking fantastic, just like the original. It adds depth and mystery to the night sky.
```

The robot acknowledged the issue faced by the participant and responded accordingly. Furthermore, to assist the participant, the robot offered a suggestion to resolve their issue:

```
Robot: Perhaps you could try a medium-sized brush for a more expressive stroke, or a small brush for delicate details.
```

Another instance when the robot came to participant's aid is mentioned in the following conversation:

```
Participant: Well, I love the painting because it looks cozy but it's harder to paint.
Robot: How about we add some texture to the walls with a smaller brush size? Small brush strokes can help create a more realistic look for the textured walls.
```

The robot considered the resources available in the Android application and offered suggestions based on those resources. However, there have been instances when the robot failed to provide suggestions even when asked, due to glitches in the system. Therefore, the system could be further improved to prevent such situations.

5.4.7. Showing love and support

Since the robot was instructed to maintain a pleasant tone throughout the conversation and to be attentive to emotional aspects, it successfully acknowledged the feelings of participants while also cheering them up and boosting their confidence. For example, when the robot suggested that a participant use a small brush size and the conversation went as follows:

Participant: Okay, but this is very small

Robot: You are absolutely correct; the brush might be too small for adding texture. No problem! We can easily increase the brush size and add more impactful strokes. Would you like me to help adjust the size?

Conversations like these provide a supportive and encouraging atmosphere for participants, enhancing their painting experience.

5.5. Use of tablet for painting

During the interview, participants were asked an additional question, "**How did you find using a tablet for painting? Was it comfortable for you?**" This question aimed to assess the feasibility of using a tablet in this experiment and to understand its potential future applications in the project.

The responses from the participants indicate a range of experiences and preferences regarding the use of a tablet for painting. Two participants found it easy and were comfortable with it, with one of them mentioning their prior experience with the tablet:

"It works, it's different for everyone but I'm used to working with a tablet"

Another two participants preferred traditional methods such as paper or a canvas and paintbrush. One participant highlighted some challenges with precision and sensory experience on the tablet but acknowledged its ease of use and cleanliness compared to traditional painting, stating:

"I would prefer a real set up but it would be a mess. It is a better tactile and sensory experience. But the robot might get damaged because of the painting."

One participant enjoyed the cleaner process, and another was indifferent to the medium used.

Overall, while some participants found the tablet feasible for the experiment, others expressed a preference for traditional painting methods. These insights suggest that while tablets are a viable option for painting activities with older adults, offering both digital and traditional options could cater to varied preferences and enhance user experience in future projects.

5.6. Overall motivation

The overall motivation was assessed by checking the duration for which the participants painted. Table 5.1 shows the duration of each participant's session.

Since we do not have enough participants in all categories, we cannot draw solid conclusions. However, we observed in this research study that participants in categories C1 and C1 painted for the same average duration. Although the allotted time for the painting activity was 15 minutes, participants in these two categories painted for extra time. This suggests that even those who were not initially inclined to paint but were open to trying it found the activity interesting enough to request additional time.

Participant		Duration	Average Duration
Category C1	P1	32 minutes and 6 seconds	23 minutes and 12 seconds
	P2	15 minutes and 44 seconds	
	P4	21 minutes and 24 seconds	
	P7	23 minutes and 33 seconds	
Category C2	P3	28 minutes and 5 seconds	26 minutes and 24 seconds
	P5	26 minutes and 58 seconds	
	P6	24 minutes and 9 seconds	
Category C3 (P8)		9 minutes and 47 seconds	9 minutes and 47 seconds

Table 5.1: Session time for participants

6

Discussion

This section covers the significance of the research and its potential applications. Furthermore, it delves into key findings, answering the research questions, challenges faced during the research, research limitations, and future work.

6.1. Significance of the Research

Dementia is a condition affecting millions of people worldwide [92], and the workforce available to provide quality care for those with dementia is decreasing [59, 29]. This research aims to address the growing challenge of providing quality care and companionship to PwD. Social robots have shown promising results in assisting PwD [41, 47, 30]. Additionally, art activities have been shown to help PwD express their emotions and improve their quality of life [16, 94]. Moreover, PwD still retain their procedural learning and procedural memory, which can aid in painting [57]. Therefore, by integrating social robots into the caregiving process, particularly through art activities, this research seeks to enhance the quality of life for PwD by promoting engagement, emotional well-being, and a sense of companionship. The findings could lead to innovative care strategies that alleviate the burden on caregivers, providing them with much-needed support and reducing their workload. Ultimately, this study has the potential to contribute to the development of empathetic and effective technological solutions that enrich the lives of both PwD and their caregivers, creating a more humane and supportive care environment.

6.1.1. Potential use with PwD

One important aspect observed during the research was that the robot guided the participants during the painting process and provided help when needed. However, the dialogues were not completely aligned with the conversational needs of PwD, as some statements were not short and simple, which is a major requirement for conversing with PwD [73, 81]. Despite this, the robot utilized its memory to provide feedback and validation to the participants. Therefore, with a better dialogue system, this robot could be deployed in care homes to support PwD in painting activities.

One participant, who worked as a caregiver in geriatrics and with PwD, provided valuable insights into how the system could benefit these individuals. They described how residents in care facilities became attached to the "Paro" seal [19] and suggested that Milo, the robot used in this research, could be designed to look like a small grandchild and interact with them. They added that Milo, being a friendly companion, could alleviate feelings of loneliness among residents in care facilities. With caregivers often occupied with numerous tasks, Milo could provide valuable engagement and support, benefiting both residents and caregivers alike.

6.1.2. Key findings

Given below are some of the key findings we obtained in this research:

- The robot was able to engage participants who like to paint or those who don't like to paint but were open to trying it (Categories C1 and C2 respectively). Although the session was scheduled

for 15 minutes, these participants often painted for a longer time. This suggests that the system has the potential to effectively engage participants, including those who may not initially enjoy painting but are willing to give it a try. The system can be further refined to make it faster, which could enhance its ability to engage people even more. However, it was completely ineffective for people who do not enjoy painting at all and are not open to trying it.

- Most participants mentioned that they found the most helpful feature of the robot was its ability to provide suggestions while they painted. This is particularly important with PwD because it can enhance their engagement and creativity, offering them guidance and support throughout the activity.
- There was a single instance when the participant and the robot were out of sync regarding their perceptions of the painting. This discrepancy led to some confusion, highlighting an intriguing aspect for further research: resolving conflicts in human-robot interactions.
- A very important finding from the interview analysis is that participants felt autonomous in their decisions. The robot provided suggestions on the painting activity, but participants chose to either use or ignore these suggestions. This is an important aspect of human-robot collaboration, as it ensures that individuals do not feel that the robot's words are being imposed on them.
- An interesting observation was made while reviewing the participants' paintings. Screenshots were taken every 45 seconds to study their engagement in the activity. Most participants displayed a common pattern of painting one section of the image before moving on to a different section. However, one participant exhibited a very different progression, randomly painting different parts of the image and moving back and forth to finish the sections they wanted to paint.

This observation reveals different styles and approaches to engagement in painting activities, suggesting individual differences in cognitive processing, attention span, or personal preferences. Recognizing and adapting to these varying engagement styles could enable the robot to provide more tailored support and guidance, increasing its effectiveness. Future research can use these insights to personalize the robot's interactions and suggestions. By accommodating different engagement styles, the robot can become more adaptive and responsive, enhancing participants' overall experience. Additionally, studying these patterns can provide valuable insights into the cognitive and behavioral traits associated with different painting styles, aiding in the development of more sophisticated and personalized robotic systems. Furthermore, a similar analysis of the paintings over a longer period of time may help caregivers understand the progression of dementia. More research is needed to explore how these engagement styles influence the activity's effectiveness and to better understand participants' cognitive processes.

- An essential aspect of human-robot communication is the robot's ability to recognize and correct its mistakes. During our research, we observed an instance where a participant corrected the robot's error, and the robot promptly apologized and clarified with the participant. This responsiveness is crucial as it enhances the robot's reliability and fosters trust in its interactions with users.

6.2. Answering Research Questions

In this section we aim to answer the research questions based on our findings in Section 5.

6.2.1. Restating RQ1

How does incorporating episodic memory and visual short-term memory in a social robot affect the following aspects during interactions with older adults?

- **Engagement in conversation**
- **Sense of companionship**
- **Valence of emotional state**

Engagement in Conversation:

Incorporating episodic memory and short-term memory in a social robot had varying effects on older adults' engagement in conversation. The robot had somewhat positive effect on participants who like

to paint (C1) and those who did not like painting but were open to trying it (C2). Participants in both categories C1 and C2 engaged in conversations with the robot. However, the robot's memory had no impact on the single participant from Category 3, who was not inclined to talk to the robot and occasionally avoided its comments.

Sense of companionship:

Mixed results were observed regarding the sense of companionship among participants in categories C1 and C2. The single participant in category C3, however, did not feel any sense of companionship. Nonetheless, most participants across all categories acknowledged feeling understood and listened to by the robot.

Valence of emotional state:

Most participants across all categories felt that the robot reacted to their emotions and adapted accordingly. During the interaction, most participants either remained neutral or became more relaxed and felt better. However, a few participants who felt neutral during the conversation felt good afterward, indicating that the activity can positively impact participants' moods. Furthermore, no participant felt frustrated by the robot. Hence, we can suggest that the robot had a generally positive effect on participants' emotions.

6.2.2. Restating RQ2

How does introducing an art activity program facilitated by a social robot affect the engagement levels of older adults in the activity?

The extent to which the social robot affected the engagement levels among older adults in the painting activity depended entirely on their category, that is, their interest in the painting activity. All participants in C1 (participants who generally enjoy painting) enjoyed painting with the robot, with most of them mentioning they would have painted for a shorter time without the robot and that its presence positively impacted their artwork. However, only some participants in C2 (participants who don't like to paint but were open to trying it) enjoyed painting with the robot, but all of them stated that its presence did not affect their artwork. Additionally, some participants mentioned they would not have painted longer without the robot. The participant in C3 did not enjoy painting with the robot, as they were completely disinterested in the activity and unwilling to paint.

All participants from category C2 found the presence of the robot interesting and novel, whereas only some participants in C1 found it interesting. The participant in C3 did not find the robot or the activity interesting at all, and the robot failed to motivate this participant. However, most participants in C1 and C2 felt motivated to paint by the robot. Furthermore, based on the painting progression, participants in C1 and C2 effectively engaged in painting on the tablet, while the participant in C3 showed poor task engagement.

Therefore, we can conclude that the art activity facilitated by the social robot largely depended on the participants' interest in painting and their willingness to paint. The robot had a slight positive effect on people who liked painting and those who did not like it but were open to trying. The idea of painting with the robot was found to be interesting and motivating by some participants. However, the robot had no effect on those who disliked painting and could not spark any interest or motivation in them.

Furthermore, the average duration of a painting session for people in C2 was almost the same as that of C1, indicating that even though they disliked painting, they dedicated their time on painting activity. Thus, we can suggest that the activity can be beneficial for people who are willing to paint, regardless of their initial interest in painting. However, increasing the number of participants will provide us with a more comprehensive insight into this finding.

6.3. Challenges

6.3.1. Challenges with the Robot

The robot was chosen after proper analysis and it initially performed well. However, in the later stages of development, it started showing errors, likely due to a mechanical fault in its neck movement. The

robot could speak, but if its head moved, it would eventually stop working. To improve engagement, the robot's head was meant to move continuously to make eye contact with participants. However, due to the head movement error, the robot's head remained still during the experiment. This may have led to some participants commenting that the robot needed to be more human-like. Maintaining eye contact is crucial while talking to a person, so this issue could have impacted the experiment.

6.3.2. Challenges during the experiment

During one of the experiments, the WiFi stopped working for a few minutes. Internet connection is crucial for this setup, as the robot is connected via wireless LAN, and any interruption could disconnect the robot from the system. Additionally, the APIs stopped working during this period. The entire setup had to be restarted, and the experiment was resumed. This interruption could have led to deviations in the results and a different experience for the participant.

6.3.3. Research Limitations

Given below are the limitations of this research:

- Recruitment of participants: The conversations with the robot and the interviews are currently conducted in English because LLM perform best in this language [17]. However, recruiting elderly participants proficient in English has been challenging in the Netherlands. Developing multilingual support for the robot would allow it to cater to a more diverse population. Incorporating speech recognition and response generation in multiple languages would make the program accessible to non-English speakers. This would likely improve participants' comfort and engagement, potentially leading to better results. Additionally, due to the limited number of participants, the results may not be entirely accurate. Therefore, a major focus of future work should be on expanding the participant pool to obtain more comprehensive and reliable data.
- The robot's speech recognition is still not perfect, so even slight mistakes in understanding the user's speech can disrupt the entire memory model, leading to incorrect results. To ensure accurate memory formation, the user's input were manually entered into the robot in real time. This added to the conversation lag, as typing was not as fast as the user's spoken words.
- Due to numerous operations involved in analyzing the robot's memory and the continuous addition of new data in real-time, the system tends to slow down sometimes, causing the robot to take longer to respond. Optimizing the algorithm and utilization of better resources to address this issue can be part of future work.
- Since the LLM could not be trained on a dataset consisting of conversations with PwD, the responses generated were not always precise or suitable for conversations with PwD, as discussed in Section 3.1.
- Sometimes, the robot had difficulty detecting sarcasm, causing ambiguity in responses as it would take participants' jokes seriously. Improved artificial intelligence capabilities are crucial for enhancing communication and understanding subtle interactions in such scenarios.
- A video analysis of the painting session would provide deeper insights into the participants' engagement levels in the conversation and the activity. However, due to ethical concerns, video recording of the sessions could not be conducted.
- The developed Android application did not accommodate users with color blindness or vision issues. As a result, color-blind users may have difficulty selecting colors, and elderly users with poor vision need accessibility features enabled in the application. For example, the tablet could announce the color when a user selects it. Adding such accessibility features to the Android application would be very helpful in these scenarios and can be considered for future work.

6.4. Future work

- One major feedback from participants was that the robot's response time was sometimes slow. Optimizing the code and using different computational resources can improve the robot's response time. Additionally, integrating speech recognition can make the conversation process more seamless, reducing lag caused by real-time typing during the session.

- The conversation style of the robot could be tailored for different groups: those who like painting, those who don't like to paint but are willing to try, and those who dislike painting without any willingness to try.
- Instead of mandating the use of a tablet, offering both a tablet and a canvas could cater to a wider range of preferences.
- Providing multilingual support to the robot would allow participants to speak in their native language, making them more comfortable when interacting with the robot.
- Conducting longitudinal studies would help observe the long-term impact of using a social robot in art activities, aiding in understanding how sustained interactions affect engagement, emotional well-being, and cognitive health. The robot can also be used for multiple sessions with participants to better understand their personal preferences, enabling more personalized future interactions. For PwD, analyzing their paintings over time can help medical professionals track cognitive function and note any decline or improvement. Additionally, studying the cognitive and emotional benefits of engaging with the robot in art activities can include assessments of mood, memory, attention, and overall mental health before and after participation in the program.
- Even though the LLM was instructed to keep responses concise and simple, there were moments when it ended up generating long and complex responses. Therefore, it is crucial to train the LLM on datasets specifically consisting of conversations with PwD. This specialized training can lead to better and more tailored responses from the LLM for systems designed for PwD.

7

Conclusion

The research investigated how incorporating episodic memory and visual short-term memory in a social robot affects older adults during an art activity. The findings indicated that the social robot had a moderately positive influence on engagement levels in both conversations and painting activities among participants who enjoyed painting and those who didn't like painting but were open to trying it. These participants demonstrated high engagement, interacting dynamically with the robot, and appreciated its relevant and structured suggestions. However, participants who disliked painting and had no inclination to try exhibited low engagement, indicating that the robot's features had limited impact on those inherently disinterested in the activity.

In terms of conversational engagement, the robot's ability to remember and recall details improved the quality and personalization of interactions for most participants, making conversations smoother and more engaging. Participants felt that the robot's memory capabilities made interactions more personal, although some expressed concerns about privacy and the future implications of robots with memory. Even though most participants enjoyed conversations with the robot, there were instances where the robot did not consistently adhere to communication guidelines for people with dementia, occasionally responding with complex and lengthy statements. Addressing these issues would significantly enhance the system's effectiveness and user satisfaction.

The episodic memory model proved effective in most instances. By recalling specific memories and posing contextually relevant questions, the robot sustained coherent dialogue and enhanced the painting activity. The short-term memory model also proved effective in providing immediate, relevant feedback that enhanced participants' engagement and motivation. By observing and commenting on the differences in the paintings, the robot offered real-time encouragement and specific praise.

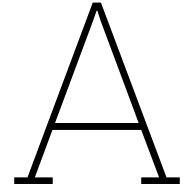
Regarding the effect of the robot on the emotions of the participants, most were generally positively influenced, with none expressing frustration. Many participants felt neutral or maintained a positive mood during interactions, and some reported feeling better afterward. However, the robot did not foster a sense of companionship among the participants, indicating a need for further research to enhance its capability as a companion for people.

Interestingly, most participants highlighted the robot's ability to provide suggestions as its standout feature. While many appreciated these insights, some chose to only partially use them or not use them at all. This indicates that while the robot offered insights, participants felt autonomous in their decision-making—a crucial aspect of human-robot interaction.

However, the robot's response time and occasional lack of real-time awareness were noted as areas needing improvement. Despite this, the study suggests that the social robot had slight positive effects on engagement for those who enjoy painting (C1) and for those who did not like to paint but were open to trying it (C2). Specifically, participants in Category C2 demonstrated a significant impact from the robot's presence, leading to longer painting sessions that averaged the same duration as those of participants who enjoy painting. Yet, the robot has no impact on individuals who have no inherent interest in the activity and are also not willing to try (C3), focusing that the robot was unable to motivate

them to paint at all. Because the study involved a limited number of participants, the results may not be entirely accurate. Consequently, future research should aim to expand the participant pool to obtain more comprehensive and reliable data.

Lastly, for the memory feature to function effectively, the robot needs to engage in meaningful conversations with the participant to form memories. The effectiveness of this memory formation depends on the type of responses provided by the participant and the length of the conversation. If the participant responds with only short answers and lacks detail, the robot cannot adequately form memories to enhance subsequent interactions. Moreover, if the conversation is too brief, the robot may not have enough time to form and utilize memories effectively. This limitation could potentially lead to a bad painting experience. Therefore, future research should focus on adapting the robot to different conversational styles to enhance its ability to provide a more fulfilling painting experience.



Appendix

Table A.1: RQ1 reasoning for main and probing questions

S. No	Question	Reasoning
1	How did talking to the robot affect your experience during the painting activity?	Main question needed for the research question
2	Did it feel like you were painting alone or as if you were painting with someone?	To explore the participant's sense of companionship and whether the robot mitigated feelings of loneliness.
3	How did the robot respond to things you said during the painting? Did it seem to understand you?	To assess the robot's perceived responsiveness and understanding, which contribute to a sense of companionship.
4	Did you notice the robot reacting to your emotions while you painted? Can you explain a situation?	To determine if the participant perceived the robot as emotionally aware and responsive.
5	Was there ever a moment when the robot's actions or responses frustrated you? What happened?	To identify any negative interactions and understand the reasons behind them.
6	How was your mood change during your interaction with the robot?	To evaluate the immediate emotional impact of the robot's presence and interactions.
7	Did your mood change after interaction with the robot? How?	To understand the lasting emotional effects of the interaction, post-engagement.

Table A.2: RQ2 reasoning for main and probing questions

S. No	Question	Reasoning
1	Did you enjoy painting with the robot? What did you enjoy most?	Main question needed for the research question
2	Do you think having the robot there affected how long you spent painting?	To determine if the presence of the robot influenced the duration of the painting activity, indicating its impact on engagement levels.
3	If the robot wasn't there, do you think you would have painted differently or felt differently about the painting?	To understand the comparative effect of the robot's presence on the participant's painting behavior and emotional response, providing insights into the robot's role in the activity.
4	What aspects of painting with the robot did you find helpful?	To identify specific features or interactions with the robot that contributed to a positive painting experience, highlighting areas that enhance engagement.
5	Did the robot's suggestions influence how you painted? Can you describe how?	To assess the direct impact of the robot's input on the participant's engagement and creativity.
6	Did you feel that the robot's comments were relevant to what you were doing? Can you give an example?	To determine the perceived relevance and helpfulness of the robot's comments.
7	Did the robot's suggestions influence how you painted? Can you describe how?	To evaluate whether the robot's presence increased or decreased the participant's interest in the activity.
8	In what ways did the robot motivate you to continue painting?	To understand how the robot's interactions influenced the participant's motivation and persistence.

Table A.3: Robot's memory: reasoning for main and probing questions

S. No	Question	Reasoning
1	Did you feel that the robot remembered things from earlier in your conversation?	Main question needed to study episodic memory
2	How did it make you feel?	To understand the emotional impact of the robot's memory capabilities on the participant, indicating how memory recall affects participant's comfort and connection.
3	How did the robot's ability to remember affect your interaction?	To evaluate how the robot's memory influenced the overall interaction quality, revealing its impact on engagement and participant's satisfaction.
4	Do you think the robot's ability to recall previous details made the conversation more personal? Why or why not?	To determine if memory recall contributed to a more personalized experience, indicating the effectiveness of episodic memory in creating meaningful interactions.
5	Did the robot seem to know what you were painting?	Main question needed to study short term memory
6	Did the robot make relevant suggestions to what you were painting?	To assess the accuracy and relevance of the robot's short-term memory in providing useful feedback, which indicates the practical effectiveness of its memory.
7	Was the robot aware of your painting progress? How did it make you feel?	To understand if the robot's awareness of progress enhances the participant's experience, contributing to feelings of being understood and supported.

Table A.4: Robot's episodic memory: some examples

S. No	Episodic memory instances
1	<p>When the robot inquired about the participant's progress on their painting with, "Are you feeling a bit happy and excited about your progress on your painting?" it recalled the participant's earlier statement about trembling with excitement ("yeah I like it very much, I think it's successful. I'm trembling a bit"). The participant's enthusiastic reply, "very much, I'm going speedy. the colors seem right to me," highlighted how the robot's question reinforced positive feelings and motivation. This positive reinforcement likely contributed to the participant's sustained interest and satisfaction with their painting.</p>
2	<p>When a participant talked about the elements they liked to paint, such as markets and fountains ("yes, I like market and fountain"), the robot retrieved this memory and asked, "What specific elements would you like to add to the market and fountain to make them even more lively and detailed?" The participant's answer, "I would like to add people," showed that the robot's question inspired them to think creatively about adding life and detail to their painting. This not only personalized the activity but also stimulated the participant's imagination and engagement with their work.</p>
3	<p>When discussing the sky in their painting, the participant said, "sky is still the most beautiful thing, blue is so intense." The robot asked, "Could you tell me more about what colors and details you plan to add next to further enhance the sky in your painting?" The participant replied, "well I think I used most of the colors I wanted to use." This response highlights how the robot's question prompted the participant to reflect on their use of color and consider the next steps in their artistic process.</p>
4	<p>When a participant mentioned their concern about the recognizability of their painting, "I hope it's still recognizable, all the villages, sky stars," the robot asked, "Could you describe what specific aspects of the village and sky you're focusing on to ensure they remain recognizable in your painting?" The participant answered, "well, specifically the colors have to be naturalistic." This interaction illustrates how the robot's question encouraged the participant to think critically about their artistic goals and techniques, fostering a deeper engagement with their work.</p>

Table A.5: Robot's short term memory: some examples

S. No	Short term memory instances
1	<p>A comment like "Wow, you're making great progress! I see you've started adding that iconic yellow to the moon and stars," led to the participant explaining their process: "yeah, I have started with green now on the cypress, I don't know how much yellow I can put in cypress." This detailed response shows that the robot's feedback prompted the participant to think and talk more about their artistic choices, fostering a deeper engagement with their painting process.</p>
2	<p>Comments like "Wow, you added a brown color! I really like how you are adding more details to the village at the bottom, it's really starting to take shape," elicited the response, "I hope it's still recognizable, all the villages, sky stars." This indicates that the robot's feedback helped the participant focus on the recognizability and details of their work, promoting a reflective and meticulous approach to their painting.</p>
3	<p>When the robot said, "Wow, you've added some vibrant green to the sunflower petals – it's looking more and more alive with each brushstroke!" the participant affirmed, "yes, it's true I like it." This shows that the robot's observation aligned with the participant's own perception, reinforcing their satisfaction with their progress.</p>
4	<p>Another effective comment, "Wow, the moon is now shining a bright yellow, it looks fantastic!" was met with a simple "thank you," suggesting that the participant appreciated the recognition and felt encouraged by the robot's positive reinforcement.</p>

B

Appendix

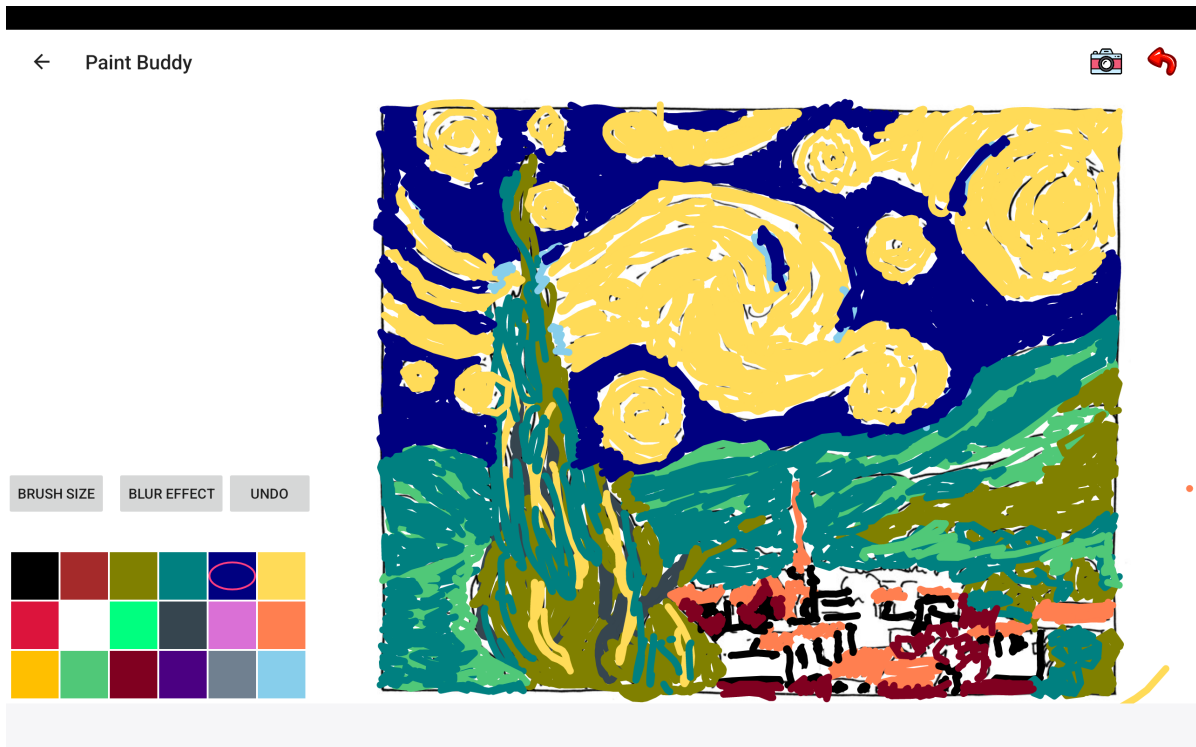


Figure B.1: Painting of participant from category 1

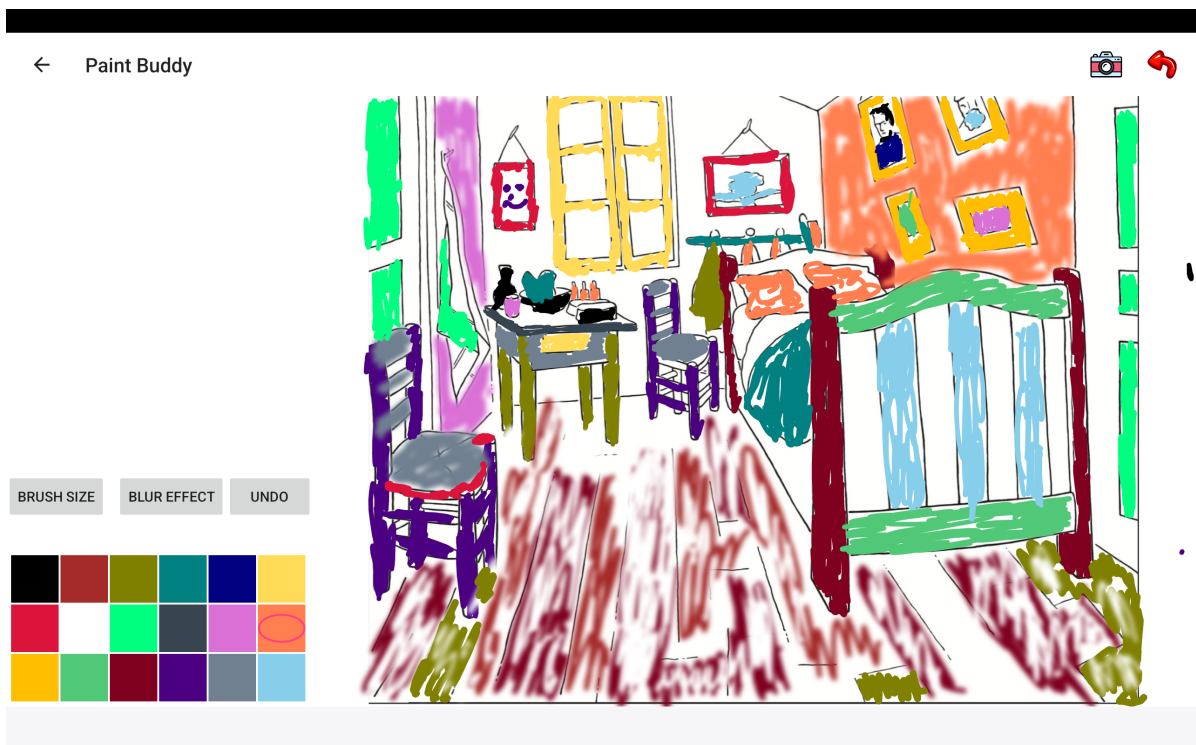


Figure B.2: Painting of participant from category 2

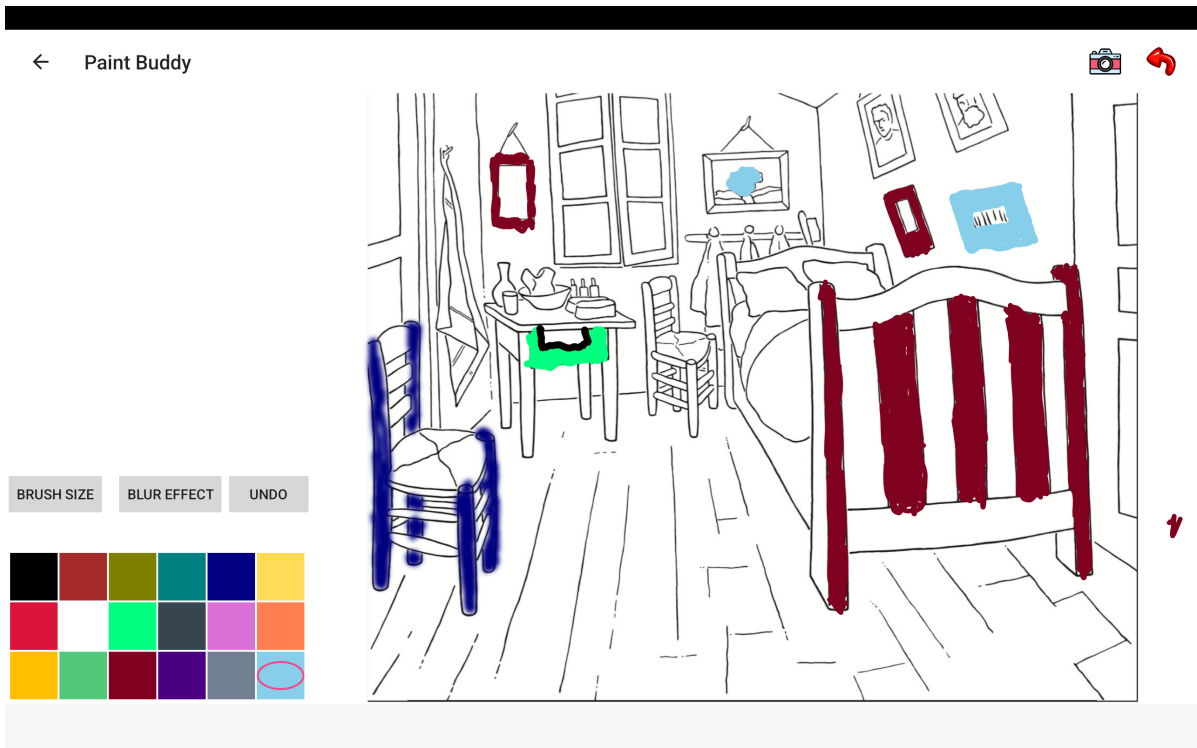


Figure B.3: Painting of participant from category 3

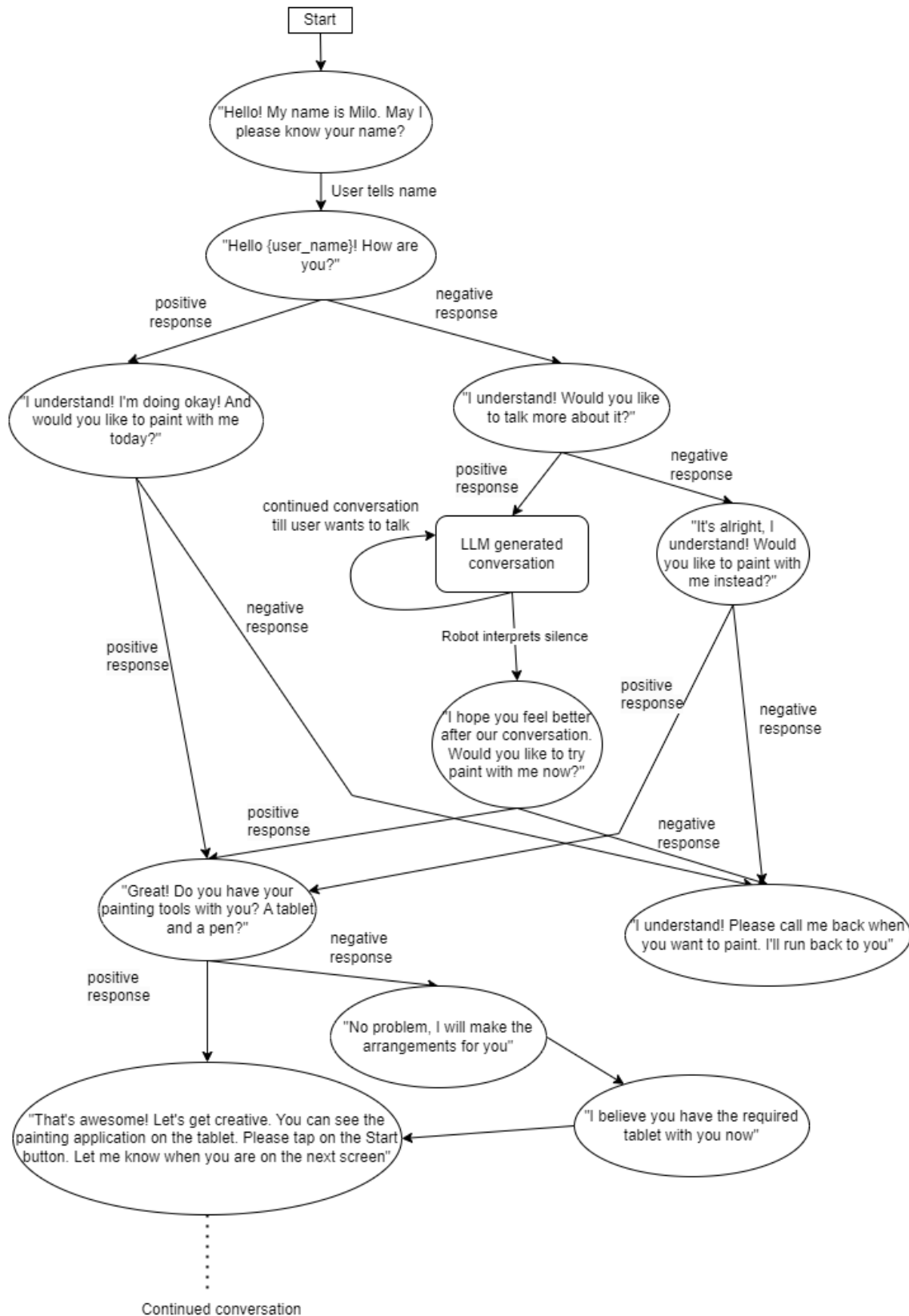


Figure B.4: Conversation flowchart: initial scripted conversation

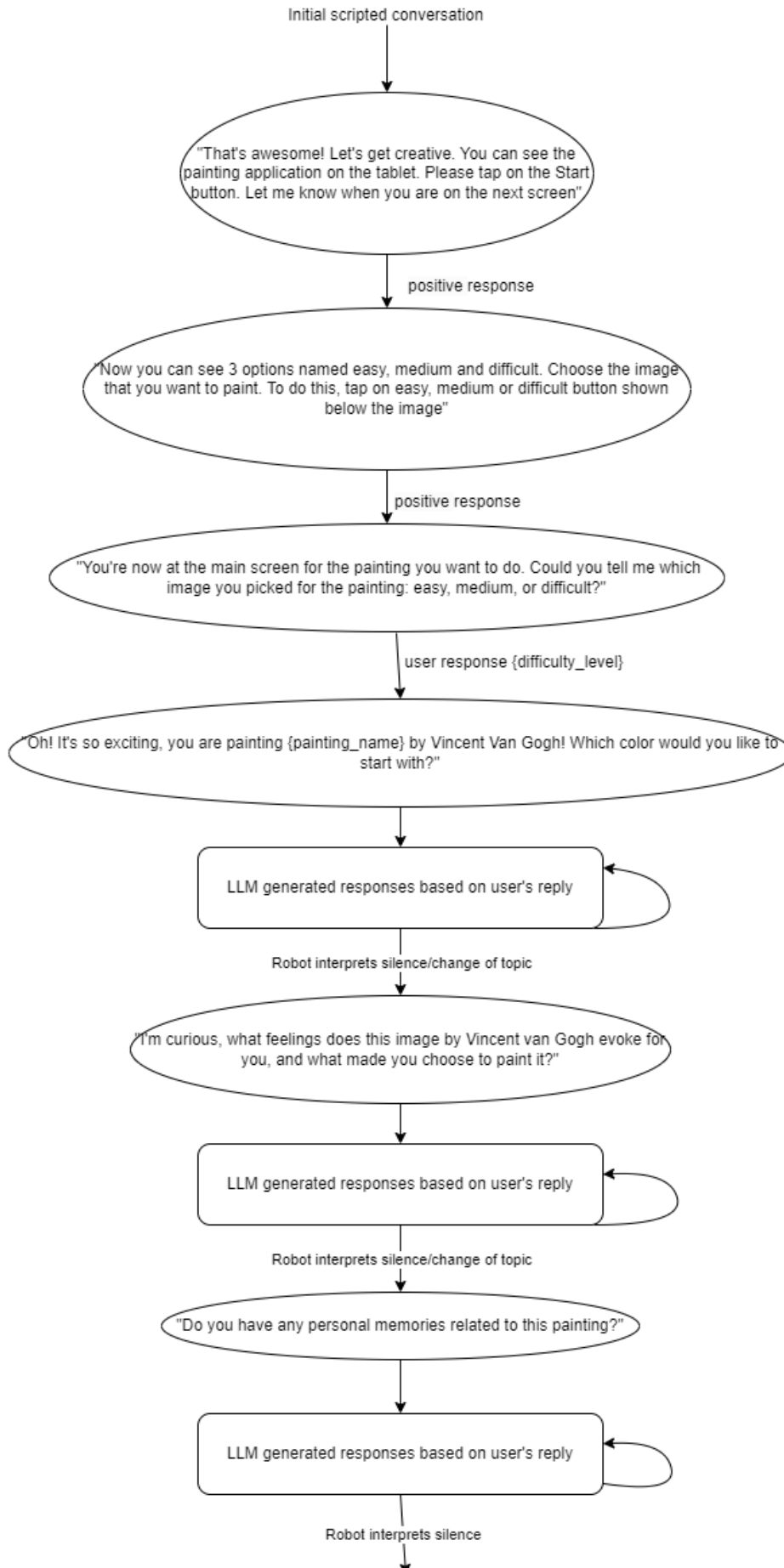


Figure B.5: Conversation flowchart: General conversation

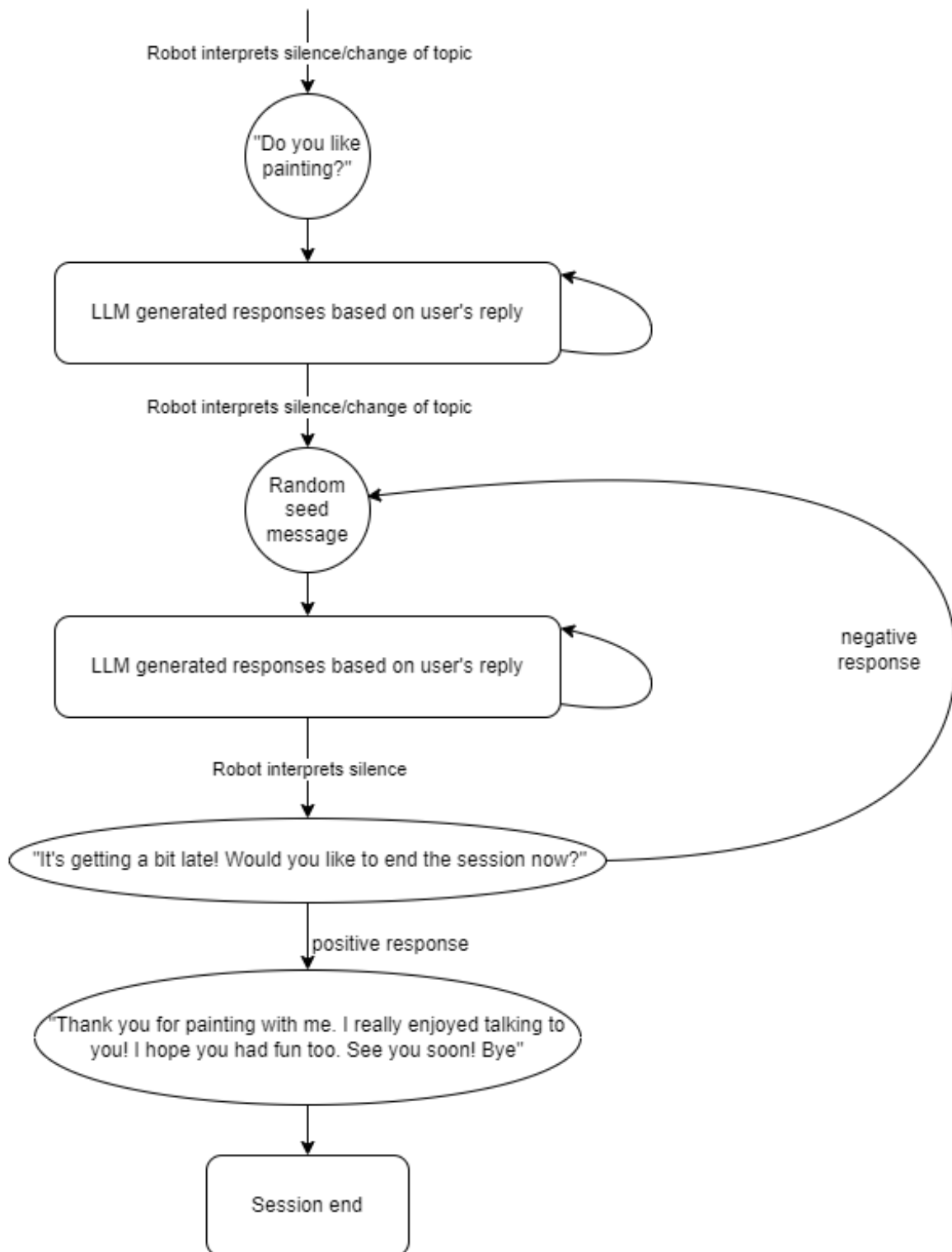
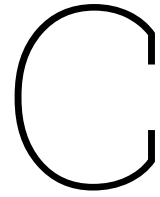


Figure B.6: Conversation flowchart: General conversation and Ending



Consent Form

You are being invited to participate in a research study titled “Designing Memory for Social Robots: Facilitating Conversations in Dementia Care during an Art Activity using Large Language Models”. This study is being done by Shambhawi Pal, Catharine Oertel and Prof Dr. Mark Neerinx from TU Delft.

The purpose of this research study is to provide companionship to elderly people with the help of a social robot during a painting session, and it will take you approximately 15-20 minutes to complete. The data will be used for evaluating our system and publishing the results if possible. The published data will not include your personal data. We will be asking you to talk to the robot and at the same time paint the image on the tablet provided to you.

As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by deleting all the data post the research study. During the session, the robot will aim to chat meaningfully with you. How much you want to tell the robot is completely up to you. The robot will only ask for your name to make the chat more personal and comfortable for you. After the chat, personal information like your name will be deleted and the data will be kept anonymous for the research study.

Your participation in this study is entirely voluntary and you can withdraw at any time. After the session, you'll receive a survey form to give your thoughts about the robot. You can also choose not to answer any question at any time.

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