Development of a Social Robot as a Mediator for Intergenerational Gameplay & Development of a Canvas for the Conceptualisation of HRI Game Design

by

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

Aishwarya K Aravamuthan was the sole author of this thesis, written under the supervision of Dr. Kerstin Dautenhahn and Dr. Jennifer Boger.

Research presented in Chapter 3

This research was conducted at the University of Waterloo by Aishwarya K Aravamuthan, under the supervision of Dr. Kerstin Dautenhahn and Dr. Jennifer Boger.

Stage 1 study Aishwarya K Aravamuthan led the study design, recruitment of study participants, and data analysis. Dr. John Muñoz contributed to the game design. Katrin Fischer contributed to the study design and helped in preparing the ethics application for the study. Katrin Fischer and Aishwarya K Aravamuthan conducted the first two sessions of the study. Dr. Shruti Chanda and Aishwarya K Aravamuthan conducted the next two sessions of the study. Aishwarya K Aravamuthan drafted the manuscript and each author provided intellectual input to manuscript drafts.

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Stage 2 and Stage 3 design Aishwarya K Aravamuthan lead the design and development of Stage 2. Dr. John Muñoz contributed to the game design. Aishwarya K Aravamuthan and Dr. Shruti Chanda contributed to the study setup. Dr. John Muñoz and Dr. Shruti Chanda helped Aishwarya K Aravamuthan with the test runs and prototype testing for Stage 2.

Research presented in Chapter 4

This research was conducted at the University of Waterloo by Aishwarya K Aravamuthan, under the supervision of Dr.Kerstin Dautenhahn and Dr. Jennifer Boger.

Aishwarya K Aravamuthan did the background research, conducted brainstorming sessions with Dr. John Muñoz and Dr. Shruti Chanda, conducted test runs with researchers, and created and revised all versions of the canvas. Dr. John Muñoz and Dr. Shruti Chanda provided input into identifying the key aspects and in the visual representation of the canvas.

Abstract

Intergenerational interaction between grandparents and grandchildren benefits both generations [18]. The use of a social robot in mediating this interaction is a relatively unexplored area of research. Often Human-Robot Interaction (HRI) research uses the robot as a point of focus; this thesis puts the focus on the interaction between the generations, using a multi-stage study with a robot mediating the interaction in dyads of grandparents and grandchildren.

The research questions guiding this thesis are: 1) How might a robot-mediated game be used to foster intergenerational gameplay? 2) What template can be created to conceptually describe HRI game systems?

To answer the first question, the study design includes three stages: 1. Human mediator Stage (exploratory); 2. The Wizard-of-Oz (WoZ) Stage (where a researcher remotely controls the robot); 3. Fully/semi-autonomous Stage. A Tangram puzzle game was used to create an enjoyable, collaborative experience. Stage 1 of the study was conducted with four dyads of grandparents (52-74 years of age) and their grandchildren (7-9 years of age). The purpose of Stage 1 was to determine the following: 1. How do dyads of grandparent-grandchild perceive their collaboration in the Tangram game? 2. What role do the dyads envision for a social robot in the game? Results showed the dyads perceived high collaboration in the Tangram game, and saw the role of the robot as helping them by providing clues in the gameplay. The research team felt the game, in conjunction with the proposed setup, worked well for supporting collaboration and decided to use the same game with a similar setup for the next two stages. Although the design and development of the next stage were ready, the COVID-19 pandemic led to the suspension of in-person research.

The second part of this thesis research focused on creating the Human-Robot Interaction Game Canvas (HRIGC), a novel way to conceptually model HRI game systems. A literature search of systematic ways to capture information, to assist in the design of the multi-stage study, yielded no appropriate tool, and prompted the creation of the HRIGC. The goal of the HRIGC is to help researchers think about, identify, and explore various aspects of designing an HRI game-based system. During the development process, the HRIGC was put through three case studies and two test runs: 1) Test run 1 with three researchers in HRI game design; 2) Test run 2 with four Human-Computer Interaction (HCI) researchers of different backgrounds. The case studies and test runs showed HRIGC to be a promising tool in articulating the key aspects of HRI game design in an intuitive manner. Formal validation of the canvas is necessary to confirm this tool.

Acknowledgements

I am deeply indebted to my supervisors, Dr. Kerstin Dautenhahn and Dr. Jennifer Boger, for their guidance and insights throughout my Master's journey. Thank you for always being there and continuously supporting me for the past two years.

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Thank you to my friends and family members for supporting and motivating me in my work.

Above all, I thank my parents, K. Aravamuthan and Jayasree Aravamuthan, for their unconditional trust and encouragement throughout my life.

Dedication

To my parents.

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List of Abbreviations

BMC Business Model Canvas

CEI Coalition Effectiveness Inventory

HCI Human-computer Interaction

HRI Human-Robot Interaction

HRIGC Human-Robot Interaction Game Canvas

ICTs Information and Communication Technologies

POMDP Partially Observable Markov Decision Proces

RL Reinforcement Learning

SAR Socially Assistive Robot

SARSA State Action Reward State Action

SDK Software Development Kit

SSI Social Signal Interpretation

UML Unified Modeling Language

VAD Voice Activity Detection

WoZ Wizard-of-Oz

WRAP Waterloo Research and Ageing Pool

Chapter 1

Introduction

1.1 Motivation and Research questions

The population of older adults in Canada is increasing, with predictions suggesting a rise to 23-25% of total population by 2036 [2]. Intergenerational interaction, specifically the interaction between grandparents and their grandchildren, reduces the social isolation in both populations [38], helping the emotional development of the grandchild [83] and increasing the grandparent's sense of companionship and satisfaction [83]. Despite these benefits, there is little research into the use of technology to facilitate intergenerational interaction. [38]. The research that exists recommends collaborative gameplay to foster intergenerational interaction, games providing excitement for both generations [67]. Although digital games (i.e., using a PC or touchscreen), can facilitate this interaction [94], older adults may not be proficient or see inherent value, thereby limiting this approach. Social robots under specific settings have been shown to foster intergenerational interaction [38]. Thus this research explores how to design and develop a social robot that might mediate a meaningful intergenerational interaction in gameplay.

The research questions of this thesis are:

1. How might a robot-mediated game be used to foster intergenerational gameplay?

2. What template can be created to conceptually describe Human-Robot Interaction (HRI) game systems?

To answer question one, the author designed a multi-stage robot-mediated study to foster intergenerational interaction between grandparent and grandchild. In this process, the author discovered that there is no structured tool to capture different aspects of this multi-disciplinary system. This discovery led to the second research question. This thesis therefore comprises two phases of research: 1) The design of a robot-mediated game for intergenerational interaction; 2) The development of Human-Robot Interaction Game Canvas (HRIGC).

1.2 Contributions of this work

It is anticipated that insights from this thesis will assist researchers in designing games involving social agents and add to the information researchers can use in studying intergenerational interaction.

The main contributions of this thesis include:

- The pilot exploratory study conducted in this research suggests that a social robot has a potential role in fostering collaboration within the grandparent and grandchild dyads in gameplay.
- The proposed conceptual model is designed to help researchers to identify, think about, and compare different game design aspects when using a social agent.

1.3 Thesis Organization

Scope of this thesis

This thesis work is built on the existing research from Human-computer Interaction (HCI), HRI, and intergenerational psychology.

Table 1.1 shows the organization of the chapters in the thesis and a short description of each.

Table 1.1: Thesis Organization

Chapter	**Description**
1. Introduction	Research motivation, research questions, thesis contribution, thesis organization.
2. Background	Literature review on social robots in mediating intergenerational interaction, games to foster intergenerational interaction, study design, conceptual modelling.
3. Design of robot-mediated intergenerational gameplay	Design of multi-stage study; Stage 1 study and results; design and development of Stage 2 and Stage 3; challenges in designing a multi-stage study to foster intergenerational interaction.
4. Human-Robot Interaction Game Canvas (HRIGC)	Different elements in the robot-mediated intergenerational system and their connection; ways to represent the conceptual model and the development of the HRI game system canvas.
5. Conclusion	Summary of the research, contributions to the HRI field, limitations, and future research opportunities.

Chapter 2

Background

This chapter provides an overview of the background research. It includes the benefits of intergenerational interaction, the role of technology in fostering this interaction, background work supporting design choices, and the need for a conceptual model to describe the HRI game system. The research presented in Chapter 3 and Chapter 4 are built upon the background research presented in this chapter.

2.1 Intergenerational gameplay using social robots

Grandparent-grandchild interaction has mutual and individual benefits for both populations. Mutual benefits include: a) reducing social isolation [41], b) changing attitudes regarding age bias [32], and c)transferring information and experiences [22]. Individual benefits include the cognitive development of the child [18]. Information and Communication Technologies (ICTs), such as email and mobile phones, play an important role in message transfer, but lack social interaction [12]. Kaplan et al.'s review of intergenerational programs insists on new technologies to promote meaningful intergenerational interaction [39].

Games have always been a natural activity for grandparents and their grandchildren [86], providing a connective tool between the two age groups [28]. One common form is the digital game. Spending quality time with their grandchildren is a motivating factor for grandparents to play digital games [20]. For instance, in the *TranseCare* game, players connect through a video call and discuss and shop for items from a shopping list provided at the start of the game [21]. *Collage* is another game that links the grandparent and grandchild via mobile camera-phones and a touch-screen, synchronously displaying the same content for both players and promoting interaction by requiring manipulation of the items displayed on the screen [85]. Although digital games like *TranseCare* [21] and *Collage* [85] are designed to promote intergenerational interaction, not all older adults have the knowledge or comfort to use this technology. Therefore, providing alternatives is essential to supporting different needs and types of intergenerational game design.

In 2017, Short et al. designed a Socially Assistive Robot (SAR) system to mediate intergenerational interaction between older adults and their families [77]. They did a pilot study of some structured and creative activities with six family groups of an older-adult, adult, and child. Based on that work, they suggest that activities supporting intergenerational interaction are either the ones that have a meaningful role defined for all the participants or the ones that are adequately open-ended for the participants to choose a role in the activity [77]. Similarly, Joshi et al. studied the use of social robots in intergenerational interaction with older adults and children in non-familial settings [38]. Their research used a number of commercial robots (e.g. Paro, Joy For All, Nao, and Cozmo) in structured and unstructured activities, and their results suggest that unstructured, open-ended activities could stimulate intergenerational interaction. This work showed that social robots have a positive impact on intergenerational interaction in non-familial settings when the needs of both generations are taken into account [38].

As the work cited above illustrates, the use of technology for promoting intergenerational interaction is emerging. This research uses aforementioned research as a basis to focus on the interaction between grandparent and grandchild engaging in robot-mediated gameplay, and takes into account their recommendations, such as having a meaningful role for both the players in the gameplay.

2.2 Games designed for robot-mediated intergenerational interaction

Reis et al.'s systematic review on fostering intergenerational interaction reveals that many studies have proposed games as a medium to promote meaningful intergenerational interaction. They identified four features of game design that are commonly suggested by more than one publication, which are: a) direct communication between the participants, b) collaborative games, c) alterable game parameters, d) tangible interfaces [67].

Researchers make sure the game meets the needs and preferences of the players by using a player-centric approach [47]. This approach involves the participation of end-users throughout the design and development of the game. Previous research on intergenerational digital games to enhance the social interaction between a grandparent and grandchild highly recommends the player-centric approach to design. [47, 16]. This approach reduces the incompatibility that occurs when the designers use themselves as proxies for the players [47]. Taking this into account, this thesis research employs a participatory iterative design process.

2.2.1 Role of the robot in intergenerational gameplay

Social robots have played the role of a collaborator, mediator, and helper in multiplayer HRI games [90, 60, 37, 45].

Wainer et al. conducted a 10-week long-term study with autistic children. They used the KASPAR robot to play a computer game collaboratively with the children, using dyadic (two children) and triadic conditions (two children with the robot). The study results showed that the children had better engagement in a dyadic session after engaging in a triadic session. The conclusion of the researchers was that a social robot could foster interaction between two autistic children in gameplay [90]. Thus, a social robot can have a significant impact on collaborative gameplay.

In a study by Lemaignan et al., two children played a traditional 'domino' task with the Ranger robot, where the role of the robot is to transport the domino tile between the children. Researchers analyzed the children's engagement with the robot in normal mode and in misbehaviour mode. The study results showed that the children were more social when the robot behaved unexpectedly, in misbehaviour mode, than in the normal mode [45]. Therefore, uncertainty, to some extent, can promote engagement among the players. This thesis incorporates uncertainty into the study design by giving choices to the players during the gameplay.

Papadopoulos et al. explored robot mediation in remote human-human communication. The study involved adult dyads connected via Skype, controlling a virtual robot in a computer game in conventional mode (using keyboard and mouse) and robot mode (using a physical robot). Their results show that robot mediation works well for remote human-human communication in a computer game. Moreover, the participants found it challenging to familiarize robot control in a short period and would have completed the task efficiently with the conventional tools [60]. Using this study's insights, the author of this thesis designed the study game carefully to minimize the effort needed by the participants to use the technology during the session.

The key takeaways of the previous research are:
1) Open-ended activities and uncertainty may improve engagement among players [38, 45].
2) Robot mediation has a positive influence on human-human communication [60].

Therefore, in this thesis research, the robot-mediated intergenerational game scenario includes an open-ended activity and the use of a robot as a mediator.

2.2.2 Robot suitable for interaction with children and older adults

Tanaka et al. developed an educational application with a social robot, Pepper [82]. Pepper was developed by SoftBank robotics and is equipped with a tablet on its chest for audio-visual display [3]. Tanaka et al. observed that the display can gain the children's attention, as they tend to face the robot most of time during test trials with ten children [82]. Drawing participants' attention is considered an important factor in social interaction [74].

Saad et al. conducted a study placing the Pepper robot at the entrance of a university building; their results showed that Pepper is capable of gaining people's attention with specific behaviours such as waving and moving closer to the people [74]. Zora ZBOS Solution uses the Pepper robot to provide care to older adults in healthcare settings, including such activities as checking on patients and entertaining them during their physical activity sessions [5].

In addition to substantial experience interacting with children and older adults, Pepper has a range of capabilities, including speech and emotion recognition, and social capabilities like dancing and animated speech [29]. Pepper has been shown to enrich participants' interaction [82]. Pepper also gives researchers the freedom to program customized behaviours through the Software Development Kit (SDK) [82]. This research uses Pepper because of its capabilities and its suitability in interacting with older and younger populations.

2.2.3 Game scenario

Tangram use in HRI

A Chinese puzzle game called Tangram (see Figure 2.1) has 7 pieces – 1 medium, 2 large, and 2 small triangles; 1 square; and 1 parallelogram. A puzzle in the form of a shape will be given, and the participants must use all 7 pieces to form the right shape [11]. Tangram has been used in many HRI studies [11, 92, 63, 17, 17] and can improve focus and spatial thinking in children [42].

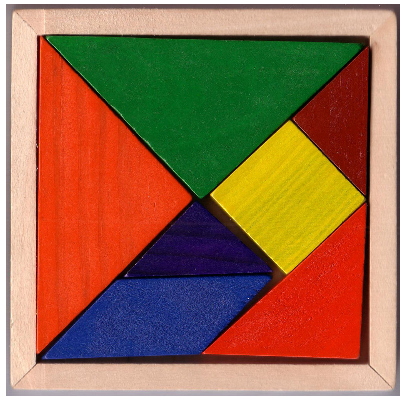

Figure 2.1: Tangram game. Reproduced from [4].

Zaga et al. examined the effect of the robot's social character on task engagement with dyadic children of the same age and gender [92]. Dyads were asked to solve Tangram puzzles at three levels of increasing difficulty in the presence of the Nao robot. To ensure both the children are involved in the game, they divided the Tangram pieces between the children. In the study, the robot acted as a Peer or Tutor, with differentiated speech and gesture to imitate the Peer or Tutor characteristics. For example, the pitch of the robot's speech was lower in Tutor mode and higher in Peer mode. The robot's role included a) giving information about the task; b) acknowledging participants' attention; c) rendering support; and d) rewarding participants for their accomplishments. The study results show that the robot in the Peer role boosted task engagement in children [92].

Bernardo et al. [9] used the Nao robot in Tutor and Peer mode with autistic children to assist them with therapy sessions. In Peer mode, the robot was an active player and took turns playing with the children. In Tutor mode, the robot gave prompts regarding the right spot for the Tangram pieces, and gave clues. Additionally, the verbal comments and gestures of the robot differed in Peer and Tutor modes. The robot's comments included pointing out the right and wrong spots, notifying the children when it was the robot's turn, and giving feedback on the children's moves. The authors found that Tutor mode worked well for children with autism in the Tangram scenario [9].

Zamani et al. [93] proposed an architecture for a robot-human collaborative task. They used a robot arm in a collaborative Tangram scenario with a combination of vision and speech for the motion planning of the robot. The robot collaborates with the human by bringing the pieces into the human's workspace. The researchers suggested that recognition of verbal and gesture commands from the human to the robot would make the session more intuitive for non-expert users [93]. The studies cited above helped to refine and create a meaningful role for a social robot in intergenerational Tangram gameplay.

Story-telling in HRI

HRI studies have used story-telling in educational applications to make the session more engaging to children [62, 76]. Costa et al. made recommendations for intergenerational digital games based on their systematic review, including interactive narratives and game contextualization [18]. Hence, this thesis research includes story-telling as a central part of intergenerational robot-mediated gameplay.

2.3 Conceptual modeling in Human-Robot Interaction

The conceptual model is defined as "a non-software specific description of the computer simulation model (that will be, is, or has been developed), describing the objectives, inputs, outputs, content, assumptions, and simplifications of the model"[p.283, [71]]. Conceptual models are meant to be used by humans and, therefore, include the psychological aspects of a system; they are intended to help a beginner achieve an overview of the system [57]. Conceptual schema can be helpful to compose ideas, categorize, and, eventually, lead to the identification of significant interdependencies [89]. In HRI, a conceptual framework should only include the elements that are feasible to implement with the robot, and should include only the elements that are recognizable by the robot [89]. To give a high-level example of what a conceptual model is, Figure 2.2 shows an example of a conceptual model of the active interface in HRI. Yamasaki et al. describe the Active interface as the system that seeks to channel the information from the user's implicit input (face expression, volume, and direction of voice) and the external environment (noise level, temperature) to act spontaneously in a given condition [91]. This representation formed the starting point for capturing the key aspects to represent an HRI Game system.

One of the most popular and efficient tools to represent a system model is Business Model Canvas (BMC) (See Appendix N) [59]. BMC is easy to use and has the comprehensive description of the key components that need to be analyzed [52, 49]. The BMC is intended to describe the key components in a simple and efficient way [6]. It is used by companies to create, communicate, and evaluate their business models [43], and key components of BMC have been used to study big data applications like smart routing and healthcare. Inspired by the BMC, researchers have proposed the canvas representation for machine learning systems, prototyping, and design research. For example, Lauff et al. [43] created the Prototyping Canvas to assist designers in planning their prototypes. Marin's machine learning canvas aims to act as a communication tool between the data scientists and developers working remotely on an existing project [49]. Nagle et al. developed the design research canvas to help the practitioners and researchers in Design Research to create and communicate mental models [6]. In this thesis, a novel canvas was created to represent HRI Game systems.

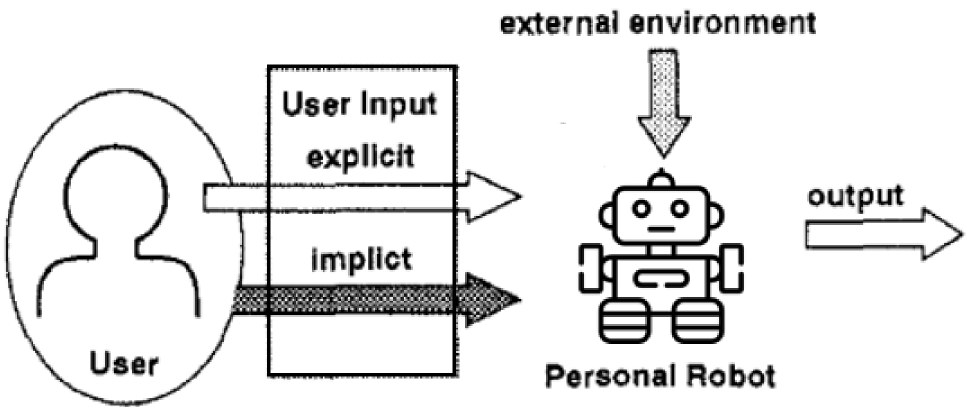

Figure 2.2: Example of a high-level conceptual model in HRI for Active Interface (Adapted from [91]).

In this chapter, the author presented prior work that is relevant to the research described in this thesis, such as the choice of game, the robot's role, and the study design. In the upcoming chapters, the research contributions of this thesis work will be discussed in detail.

Chapter 3

Design of robot-mediated intergenerational gameplay

Using a social robot to foster intergenerational interaction between a grandparent and grandchild is an area that has not received much attention in the research to date. The evidence in favour of designing games to foster intergenerational interaction using social robots is therefore limited (see Section 1.1). The iterative approach was suggested by Costa et al. for intergenerational digital games [18]. To support the design choices in this project, and to evaluate the initial design, the research team decided to create an experimental design protocol involving multiple stages that would consecutively guide the research in determining how grandparent, grandchild, and the social robot can best interact in gameplay. The research presented in this chapter also serves as an inspiration for the canvas created in Chapter 4.

This chapter describes the multi-stage study design used for robot-mediated intergenerational interaction. It includes: 1) study design, recruitment, and results of the first stage of the research; 2) design and development and the expected results of the next stage; 3) challenges in designing a multi-stage study for robot-mediated intergenerational interaction.

3.1 Design of the multi-stage study

This thesis research employed an iterative design approach to explore a social robot's use in mediating the interaction between grandparent and grandchild. The study involves three stages, each building upon the previous and increasing the robot's autonomy. The robot will have purely social interaction with the human participants, namely verbal interaction, using the tablet to display visuals, and gestures.

Figure 3.1 shows the research questions and the expected results for each stage of the study. This section describes each stage and its underlying research questions.

- Stage 1: Human-mediated

  Stage 1 involves exploratory research to guide us in designing the upcoming stages of robot-mediated intergenerational interaction. Mediation seems to work well for human-human interaction (see Section 2.2.1). In this stage, a human (researcher) mediates the interaction within the dyad of grandparent and grandchild by introducing the game to the dyad and providing help when asked. The purpose of this stage is to answer the following research questions:

  1. How do the dyads of grandparent-grandchild perceive their collaboration in the Tangram game?
  2. What do the dyads envision the role of a social robot could be in a game?

  The results of this stage guided the design and development of the next stage.

- Stage 2: WoZ

  Wizard of Oz is a popular approach used in the iterative design process. In this approach, a robot is remotely controlled by the researcher, who is hidden from the participants. This approach allows the researcher to test the initial aspects of design before full implementation [69].

  The following research questions for this stage are:

  1. What are the effects of the presence of a social robot in the gameplay?
  2. When and how should the robot interact with the dyad during gameplay?

  The insights from this stage led to the final stage of the study.

- Stage 3: Semi/Fully autonomous

  In this stage of the exploratory research, the robot is semi/fully autonomous. The research questions for this stage are:

1. How does a social robot affect the collaboration within the dyad during the game?
2. How do players perceive the game experience in terms of collaboration and fun?
3. What is the efficacy of the social robot in the game?

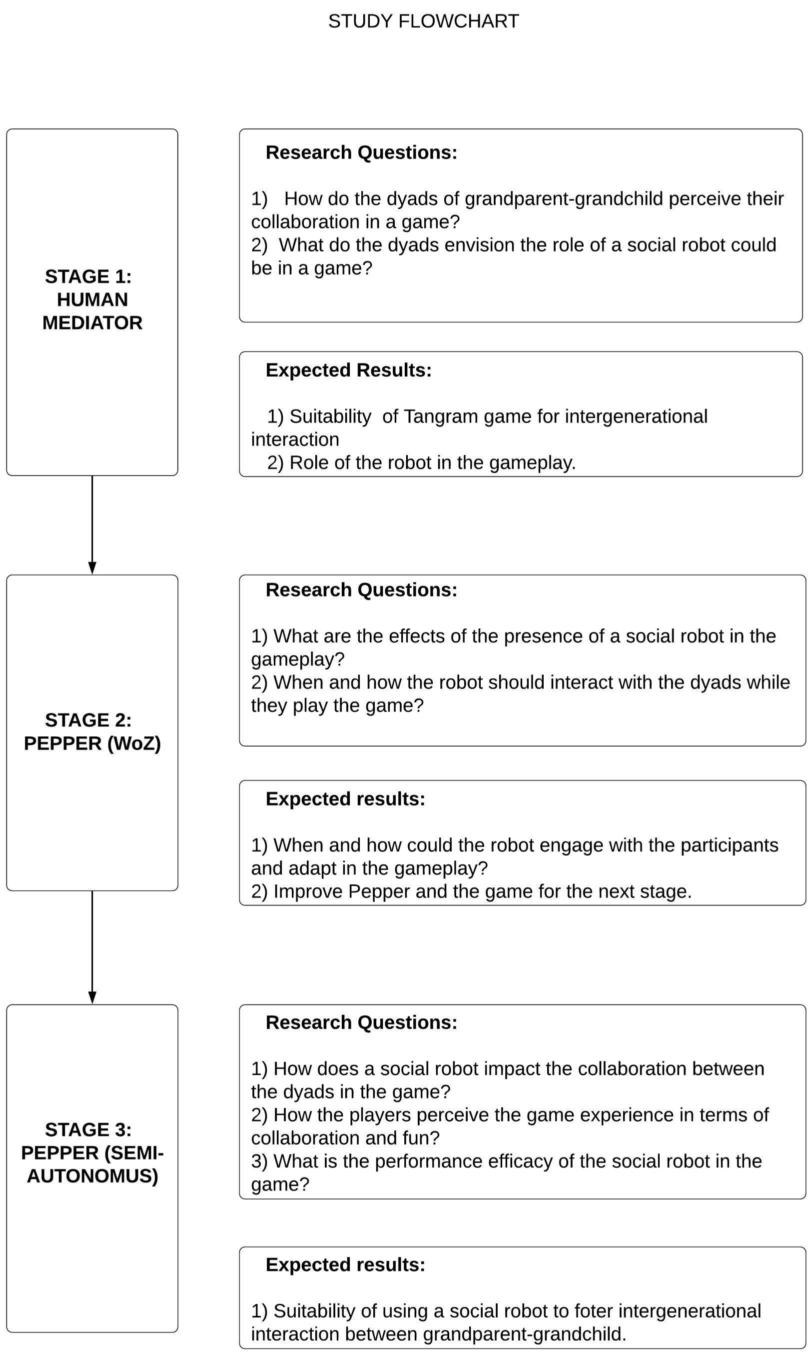

Figure 3.1: Multi-stage Study flowchart showing the research questions and expected results for each Stage.

3.2 Stage 1 study

The Stage 1 study setup and results are rephrased from my publication [8].

3.2.1 Participants and recruitment

This study was reviewed and received ethics approval through the University of Waterloo Office of Research Ethics (ORE41411). Four dyads of grandparent (aged 52-74 years) and grandchild (aged 7-9 years), who could come to the research laboratory to participate, were recruited. These four dyads also consented to participate in Stage 2 and Stage 3.

The recruitment criteria for the participants were:

Grandparent: i) age does not matter, ii) must have a grandchild (6-10 years) who can come to the study location, iii) must be able to travel to the study location, iv) should be able to understand and speak English, v) has normal to corrected vision.

Grandchild: i) 6-10 years old, ii) should be able to understand and speak English.

The recruitment process involved posting the flyers on the University of Waterloo campus (See Appendix L), and contacting older adults through the Waterloo Research and Ageing Pool (WRAP). The author recruited grandparents who met the criteria and, in appreciation of their time, the grandparent and grandchild received $10 each in remuneration.

3.2.2 Robot used

In this research, the commercially-available robot, Pepper, is used [3]. The robot is shown in figure 3.2. The research team decided to use this robot for the study because of its wide range of social capabilities and suitability for interacting with children and older adults, as described in Section 2.2.2.

Figure 3.2: Pepper robot used in this research.

3.2.3 Game

The literature mentioned in Section 2.2 suggests that game design for intergenerational interaction poses unique challenges. For example:
1) It should have minimal use of digital interfaces.
2) It should be easy to use.
3) It needs to entertain and be suitable for both generations.
4) The game should offer a medium for the participants to collaborate.
5) The game must provide a space for a social robot to play a meaningful role in the interaction.
6) The game should focus on the interaction within the dyads rather than the interaction between a robot and a human.

In seeking out a game that can address the aforementioned challenges, the research team discovered the puzzle game called Tangram. Section 2.2.3 describes other HRI studies that have used the Tangram game. This game involves arranging seven pieces of different geometric shapes to form the desired shape. To make the game more collaborative, the pieces are divided among the players. Tangram offers a collaborative play with a cognitive load suitable for both older adults and children (see the Section 2.2.3). To make the interaction more engaging and to avoid the digital interface, tangible Tangram pieces were used.

3.2.4 Study setup and protocol

Figure 3.3 shows the study setup. The first stage of the study involved two sub-tasks:

- Sub-task 1: In this sub-task, participants were asked to solve one Tangram puzzle, mediated by a human. Participants could choose from two puzzles. The role of the human mediator was to provide help to the participants when asked. This sub-task aims to see how dyads collaborate naturally in the game.

- Sub-task 2: In this sub-task, participants were asked to solve one Tangram puzzle in the presence of the robot, Pepper. As in sub-task 1, participants chose the puzzle. During the interaction, Pepper was present, but not interacting with the participants. The purpose of the robot's presence was to introduce Pepper to the participants and collect their first impressions. This sub-task aims to introduce the robot and collect the first impressions of the dyads.

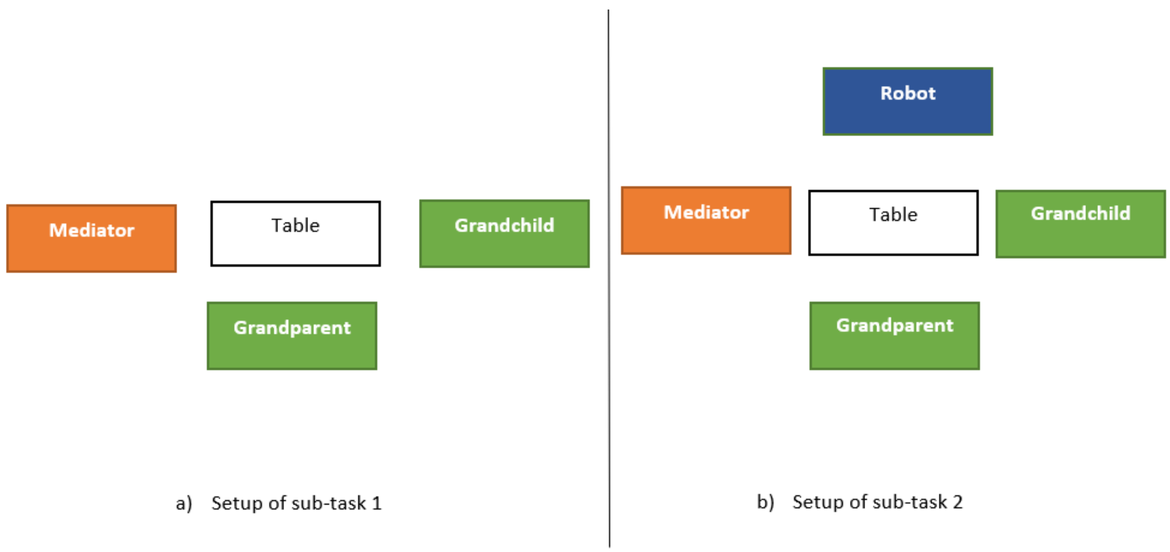

Figure 3.3: Study 1 setup: Physical locations of different elements in stage 1.

Study Protocol

Written informed consent was obtained from the grandparent and from the grandchild's legal guardian for their participation in the study (See Appendix C, Appendix D). Before the session started, verbal consent was obtained from the grandchild (See Appendix E). Each session began by asking the members of the dyad to fill out a demographic form, which included how often they play games together and what games they play (See Appendix F). After filling out the demographic form, the participants were asked to solve the Tangram puzzles in two sub-tasks. The session ended with participants answering questions on the behaviour they expected from the robot and filling out the collaboration questionnaire (See Appendix G and Appendix H). Each session lasted no more than 90 minutes.

3.2.5 Questionnaires

- Collaboration questionnaire: A self-assessment collaboration questionnaire derived from the Coalition Effectiveness Inventory (CEI) was used to measure the perceived collaboration between members of a dyad [24]. The dyads were asked to rate the experience using a child-friendly pictorial scale suggested by Miriam Donath[1] based on the standard Smileyometer [35]. To avoid the grandchild being influenced by the grandparent's answers, the grandchild was asked to rate first. The questionnaire included questions on i) teamwork: how well did the two of you work together while playing Tangram? ii) communication: how well did you communicate today? And iii) problem-solving: how well did you solve problems together?. The human mediator ensured the players understood the questionnaire and responded to any questions. To ensure that answers were not influenced by the other player, and that the dyads understood the questions, the human mediator also asked for the reasoning behind each rating.

- Post-session Questions: To explore the possible role of Pepper in robot-mediated Tangram gameplay, the following questions were asked of the dyad:

  i) Let's imagine that Pepper learned how to play Tangram from observing you today. Would you like Pepper to be here the next time you play Tangram?

  ii) Why/why not?

  iii) What would Pepper be doing?

[1]https://medium.com/@mdonath/red-and-green-when-paired-with-smiley-faces-7b065dd9d38f

For the post-session questions, the author transcribed the audio from each dyad, using video recordings, and analyzed each player separately. Similarities were identified and discussed with the research team and are presented as research insights. Since the sample size is small, no statistical analysis was performed.

3.2.6 Results

- Collaboration questionnaire: Figure 3.4 shows the dyad responses to the teamworking and communication questions on the collaboration questionnaire. For the problem-solving question, two dyads gave the rating 'okay', one responded 'Fantastic', and the other 'Really good'.

- Post-session questions: All dyads wanted the robot to be present the next time they play tangram together. For the envisioned Pepper role, most of them wanted the robot to provide help when they play the game. For example, one grandchild said,

  > *"He will help us figure it out like just step-by-step, not like to tell us the exact answers but like just slowly work through."*

  One of the grandparents responded to the same question with

  > *"We would appreciate some help when we are stuck."*

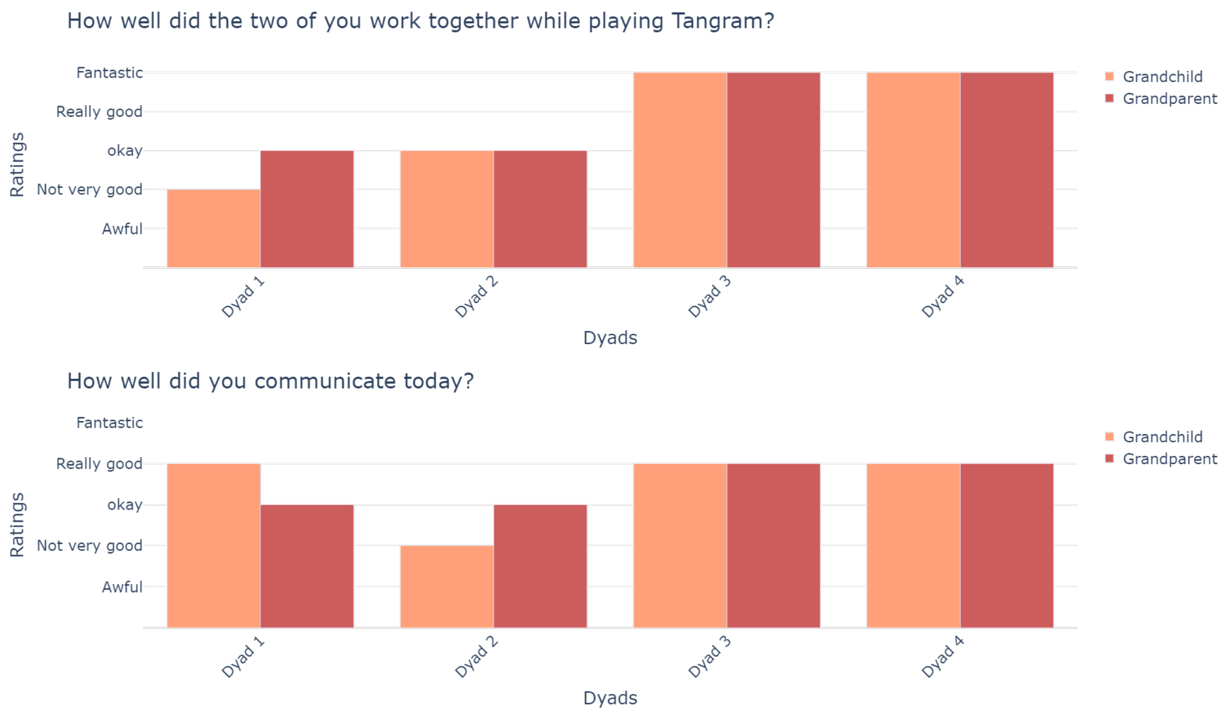

Figure 3.4: Questionnaire response of dyads in Stage 1 study.

3.2.7 Takeaways from Stage 1 study

The collaboration questionnaire results show that the dyads perceive a high level of collaboration in the Tangram game. This result indicates that the game and the setup work well for the collaborative intergenerational scenario and are suitable for upcoming stages.

During the follow-up questions, most of the participants envisioned the robot as helping them in the game. Examples of this are given in Section 3.2.6. Help was, therefore, included as one of the key roles for the robot in the next stage.

One of the grandparents described the game as,

> *"It was challenging enough, after working with shapes and collaborating with [Grandchild's name] it was good."*

Such observations suggest that puzzle-solving gameplay induces positive collaboration within the dyads, as intended.

As the robot-mediated grandparent-grandchild interaction is exploratory research, these results are needed to inform the design of the next stages. The results also reinforce the need for a meaningful role for Pepper in the intergenerational Tangram game.

3.3 Stage 2: Wizard-of-Oz (WoZ) study

Stage 1 was completed in December 2019. COVID-related restrictions meant that no in-person research was permitted as of March 2020. As Stages 2 and 3 involve co-design, they were conceptualised but not executed. The remainder of this chapter describes the work done to create the proposed stages up to March 2020. Table 3.1 shows the achieved targets and achieved milestones of the multi-stage study.

Table 3.1: Research milestones for multi-stage study

Stages	Designed and Implemented	Study conducted	Analysed and published
Stage 1	✓	✓	✓
Stage 2	✓		
Stage 3			

Stage 2 is intended to test the proposed game and robot interaction design before creating a more autonomous version and evaluating it with a feasibility study (Stage 3).

3.3.1 Stage 2 study setup

Figure 3.5 shows the setup of the Stage 2 study. In this stage, the robot will be remotely controlled by a researcher (i.e., Wizard-of-Oz; WoZ). In a WoZ setup, the researcher is hidden from the participants as a proof of concept study to emulate what people may experience in an interaction where the robot is autonomous. This allows researchers to test ideas and get feedback prior to investing the time and effort in developing the intervention, and enables them to focus on what is more likely to achieve desired goals. Stage 2 therefore aims to explore the effect of the robot's presence and see how well the robot's chosen role fits with the intergenerational gameplay between the grandparent and grandchild.

The setup includes 3 cameras: camera 1 captures the participants' reactions; camera 2 records what is causing the reaction; and camera 3 captures the participants' performance in the game. A small microphone captures verbal information. The robot would be placed across the table to maintain safe proximity from the dyad. The wizard would be hidden from the participants and would have the view of the scenario to control the robot's behaviour.

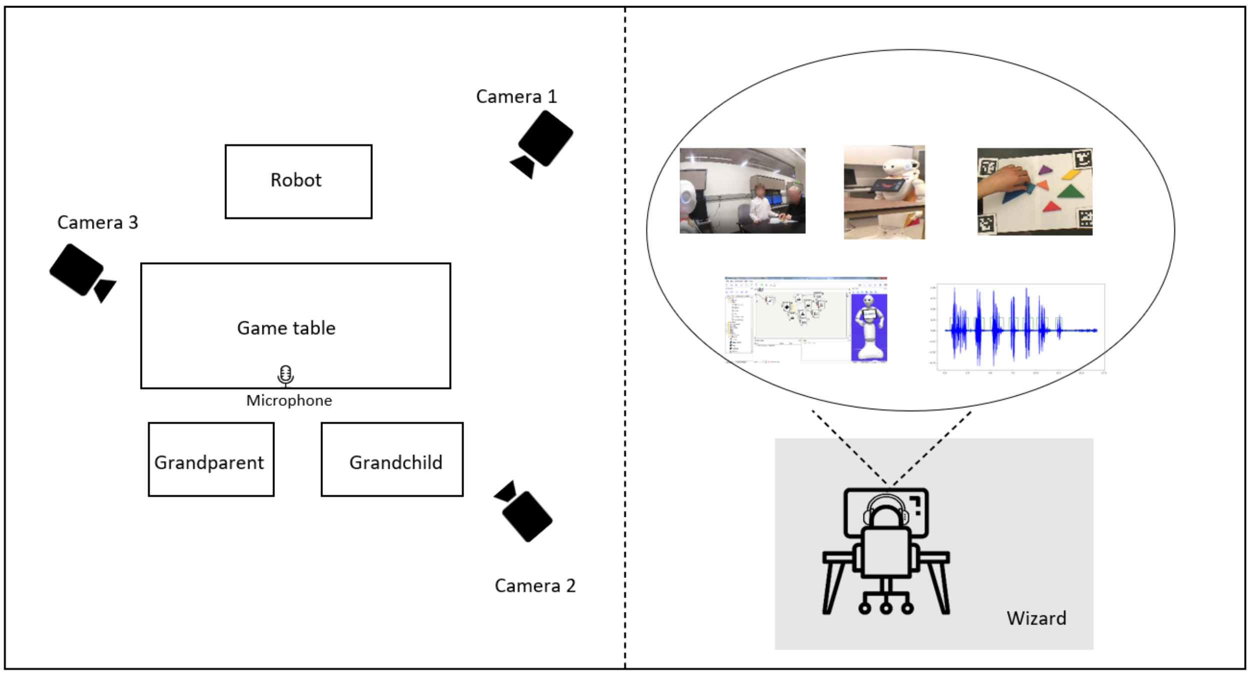

Figure 3.5: Stage 2 setup. Left side represents the physical locations of the different elements. Right side represents the wizard, with the real-time view of the game.

3.3.2 Stage 2 Protocol

Interactive elements

Involving storytelling as a part of the interaction has improved participant engagement in HRI studies with children [62, 76]. This research proposes to include storytelling as part of the interaction in Stage 2, where the Pepper robot will be narrating the story and while displaying related images as well as the puzzles on its tablet during the story. A story called 'Tangram creatures' was created based on the popular 'Grandfather Tang's story'[2]. It is hypothesised that the narrative part will bring a more enjoyable and interactive experience to the participants.

Role of the Pepper robot

Social robots helped participants solve Tangrams by giving them clues, picking up the pieces for them, and telling them the correct and incorrect pieces [9, 93]. Also, in their responses from Stage 1, all dyads wanted the robot to be present and provide help of any kind in the gameplay (see Section 3.2.6). Videos of the Stage 1 sessions showed that two out of four dyads asked for help in Sub-task 2. The author therefore assigned Pepper the role of helper to the participants in the gameplay.

To provide participants with more interactive experience while they solve the Tangram puzzle, the following behaviours are proposed for the robot:

1. To initiate the verbal communication within the dyads, the robot could say some fun facts about the shape they are solving. Animal shapes were chosen to align with the story, and facts could relate to the specific animal.

2. Positive feedback from the robot is used by the researchers in Tangram HRI scenarios [9, 92]. This inspired the researchers to propose giving positive comments on the participants' teamwork as one of the robot's behaviours.

3. During the Stage 1 study, the author observed that the participants were less engaged the harder the puzzle. The time taken by Dyad 3 to solve a puzzle in Sub-task 1 was approximately 5 minutes, and in Sub-task 2 was approximately 25 minutes for a harder puzzle. When we asked about the experience, the grandparent said,

   > *"I think it is personal, I am more fun doing less spatially challenged things than this, games like this, 3D geometry, I have trouble visualising that, so I am finding that the tougher the game is, the more challenging for me it is, so that is kind of I am not a spatial person."*

[2] https://books.google.ca/books/about/Grandfather$_Tang_s story.html?id = uh1nCbacBWsCprintsec = frontcoversource = kp_read_button redir_e sc = yv = onepageqf = false$

To avoid frustration such as this and to make the game experience more enjoyable, giving players an option to change to another puzzle was proposed.

4. These behaviours are for the robot while the participants solve the Tangram puzzle and are not meant to distract from the game. Therefore, not performing any of the above-mentioned behaviours may be appropriate at certain times. Data on collaboration within the dyads from Stage 2 would help to determine specific times. Sub-section 3.3.3 gives details on how these data could be obtained.

The aim of Stage 3 is to have the robot in semi/fully autonomous mode. Therefore, creating a simple-state machine model to decide which of the above four behaviours is appropriate during gameplay does not work, as the preference of each dyad would be different and can change over time. A protocol to tell the robot what action needs to be taken at a given instance is preferable. In order to collect data to build this protocol in Stage 2, the wizard will observe the gameplay and participants to choose a pseudorandom action at every fixed interval of time while the dyad solves the puzzle.

Figure 3.6 shows the planned protocol for Stage 2 in a sequential manner. As the figure illustrates, the session starts with Pepper narrating a story and displaying a puzzle on the tablet. After the dyad solves the puzzle, the story continues. Help and break are the options available to the dyad throughout the session. When the dyad asks for help, Pepper displays the solution for a few seconds on its tablet. When the dyad chooses to break, the session will pause for some time.

There will be three puzzles in the session, and one optional puzzle. With puzzle 1, the robot will not interact with the participants, except when asked for help. During the solving of puzzle 2, the wizard will choose one of the four actions for the robot. The reason to have one puzzle without robot intervention is to see how the dyad members feel about the robot interacting with them while they are solving a Tangram puzzle.

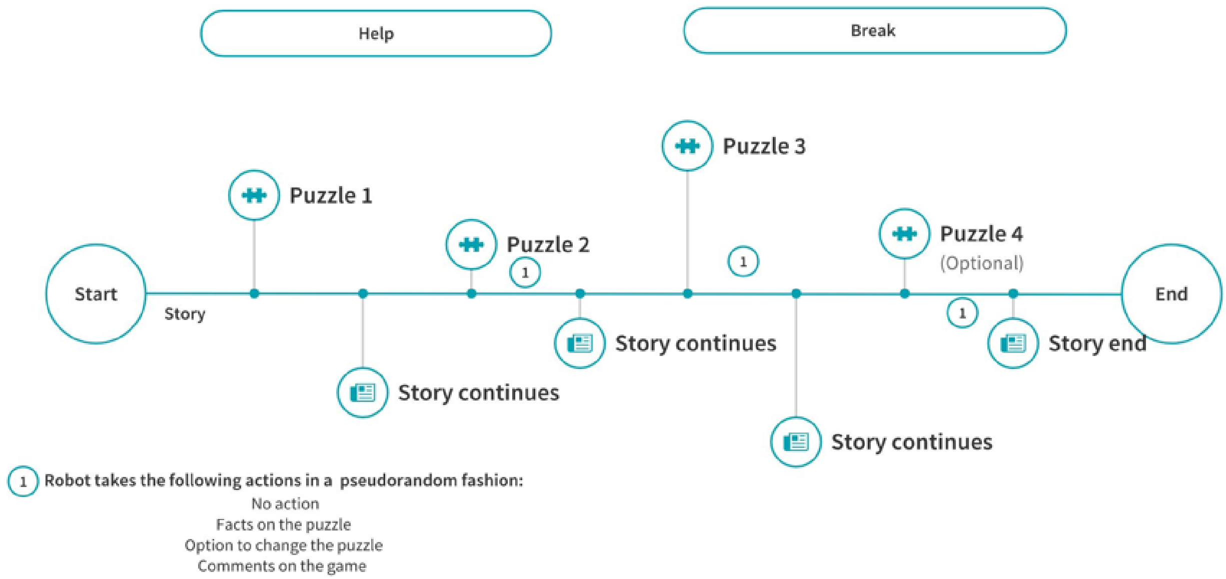

Figure 3.6: Proposed Stage 2 WoZ interaction protocol.

3.3.3 Technical development

Software

The robot behaviours for the session are designed and developed in Choregraphe[3]. This visual programming platform uses boxes and connectors. Data are read, computed, and an output is generated from the boxes, and the boxes are connected using connectors [88]. For complex custom behaviours, NAOqi APIs in Python scripts[4] were used.

Measuring collaboration

In multiplayer HRI and HCI studies, verbal communication between the players is considered one of the metrics for collaboration [60, 21]. Derboven et al. include game performance

[3]http://doc.aldebaran.com/2-1/software/choregraphe/choregraphe$_{o}verview.html$
[4]http://doc.aldebaran.com/2-4/naoqi/index.html

as one of their metrics in analyzing the collaborative intergenerational game [21]. Based on how collaboration is measured in [60, 21] and looking into what is most suitable in the context of the designed gameplay, the author decided to measure collaboration in terms of the speech and game performance of each dyad.

3.3.4 Expected results and planned design of Stage 3

This sub-section describes the expected results from Stage 2 and the planned Stage 3 design.

Expected results from Stage 2

The following insights were expected from the Stage 2 study:

- The suitability of story narration in the context of an intergenerational Tangram game. Each dyad will be asked to rate how much they enjoyed Pepper's story narration on a five-point scale.
- Unlike in Stage 1, the robot will be actively interacting with participants in Stage 2. The effects of the robot's presence on the interaction should be studied to see the suitability of robot participation in the intergenerational Tangram gameplay. Participants will be asked open-ended questions and/or be asked to rate on a five-point scale to measure the collaboration (see Section 3.2.5). Responses to the open-ended questions will be transcribed from the video data and themes will be identified.
- How to train the robot to act autonomously for Stage 3, based on the interaction data from Stage 2. The effect of the chosen pseudorandom action on the dyad's collaboration (speech and the dyad's game performance) would help the robot to decide when and which behaviour to choose during the interaction.
- How useful Pepper's help was while the dyad solved the puzzle. The participants will be asked to use a five-point scale to rate the robot's help.

3.3.5 Planned Stage 3 design

Stage 3 is the final stage of the exploratory multi-stage study and is a feasibility study. The overall game experience of the dyads and the performance efficiency of the robot in an intergenerational game will be studied in this stage. At the end of Stage 3, the author will have gained more insights to comment on the suitability of having a social robot in an intergenerational Tangram game played by a dyad of grandparent and grandchild.

For Stage 3, in addition to dyads from Stages 1 and 2, a minimum of three more dyads will be recruited to participate only in Stage 3 (see Appendix M for the recruitment flyer). The purpose of recruiting new dyads for this stage is to see how the naive dyads perceive the intervention in terms of ease of use, whether the robot supports collaboration, and if they think it is fun.

The protocol for Stage 3 is similar to that of Stage 2, but in Stage 3, instead of the wizard choosing the pseudorandom behaviours, the robot will be deciding which behaviour needs to be executed based on the dyad's collaboration in the game.

Planned decision-making

Ritchel et al. used social signals during human-robot interaction to develop an adaptation mechanism; the authors used a Reinforcement Learning (RL) algorithm called Q-learning [80] for their adaptation model [70], in which the agent/robot would observe its environment, take an action and receive a reward. Based on the reward received, the robot would evaluate the action taken. This would let the robot decide whether or not to take the same action when it encounters the same state in the future [80].

In the intergenerational Tangram scenario, the collaboration will be measured using social signals, such as the speech signal (dyad verbal communication) and game performance. Differentiating speech signals from the background noise in audio is called Voice Activity Detection (VAD) [23]. The python module VoiceActivityDetector [5] can be used to detect the percentage of speech present in each discrete interval of time. For game performance, after trying to determine an approximate ratio of the puzzle completion by detecting the basic shapes and colours using OpenCV [6] and by using the aruco markers [7] to remove the background, the author decided to have a camera focused on the game layout (see camera 3 in Figure 3.5). To facilitate the detection, pieces of seven different colours will be used so the RGB values would give the information on whether or not a particular piece is present in the layout. In addition, comparing the image captured by camera 3 (see Figure 3.5) in the previous and current interval would give the information of whether or not there

[5]https://github.com/marsbroshok/VAD-python

[6]https://pypi.org/project/opencv-python/

[7]https://docs.opencv.org/trunk/d5/dae/tutorial$_a$$ruco_d$$etection.html$

was some movement in the game, which in turn would determine whether the players were actively playing the game or not.

For every fixed interval of time during the session when the dyad is solving the puzzle, the audio chunks and the image from camera 3 (see in Figure 3.5) will be sent to a Python script, which will assess the percentage of speech signal present and whether or not the dyads are active in solving the puzzle. This would provide some information about the collaboration of the dyad for every discrete time interval.

To formulate this as an RL problem, the social signals are divided and considered the state space (i.e. speech and game metrics); the set of behaviours (i.e. the four behaviours mentioned in Section 3.3.2 available for the robot to choose at any given time is considered as the action space, as in [70]. These behaviours would be chosen by a wizard in Stage 2 to collect data to perform Q-learning during the post-analysis. Offline learning using Stage 2 data would, theoretically, allow the robot to choose appropriate behaviour autonomously to facilitate collaboration within the dyad.

3.4 Challenges in designing a multi-stage study for intergenerational interaction

Apart from the challenges inherent in research with human participants, such as applying for ethics approval and recruitment, the author faced additional challenges.

Choice of game

The dyads include different generations, with different preferences for games. For instance, older adults often prefer minimal use of a digital interface. The game should also involve physical and cognitive challenges suitable for both ages. The choice of Tangrams was made because researchers have used this game in studies involving older adults [54] and young children [9], and have found it suitable for both generations.

Technical challenges

Installing the open-source libraries on the robot was a challenge. The root account has permissions to access all the files and commands in a Linux-based system. The Pepper robot does not allow root access [8], except for shutting it down, and it does not have a

[8]http://doc.aldebaran.com/2-4/dev/tools/opennao.html

package manager. This means that Pepper does not have the flexibility to compile or install third-party dependencies like ROS. Cross-compilation with the robot OS is one way to compile the libraries, which is time-consuming and sometimes error-prone. Another way to address this is by building the libraries in a virtual machine provided by the SoftBank and porting it to the robot [66].

In Stage 2, Pepper needs to actively interact with the players for approximately 60 minutes, requiring many behaviours to be running on the robot. This can cause the robot or its tablet to crash, requiring a reboot each time. To minimize this, the author divided a behaviour into many small behaviours and ran one behaviour at a time. It still needs to be verified that this method will work in the future.

The other technical challenge was in the detection of the Tangram puzzle. As the robot will be offering help to the players when asked in Stage 2, the detection of the players' progress is important. The author tried to compare the image at discrete times with the solution of the puzzle using the feature matching techniques in OpenCV (SIFT, ORB, SURF) [73], but the detection was not good when the players solved the puzzle in a different orientation than that of the solution used for comparison. The author also tried to improve detection by removing the background, using aruco markers along with the optical flow [9]. Different solutions are suggested in the literature: Kirschner et al. used an industry-based pattern matching tool called PatMax [10] [14]; Joo-Haeng Lee proposed pose estimation of coloured Tangram pieces using a concept similar to Hausdorff distance (distance between two shapes to measure its proximity) in Mathematica [44]; Menendez et al. used a sequence of filtering and segmentation processes to recognize the coloured Tangram pieces in different height and illumination conditions [53]. However, since, extensive work on Tangram detection is beyond the scope of this thesis, the author decided to simplify the process by comparing the gameplay images in two time frames and using changes to indicate the players' involvement in the game.

Recruitment

The author recruited grandparents who could come with their grandchildren (who were 6-10 years old) to the University of Waterloo. Recruiting this population was challenging, as the parent's permission was needed for the grandchild's participation. For the Stage 1 study, the author contacted approximately 60 older adults by phone and email. Some

[9] https://docs.opencv.org/trunk/d5/dae/tutorial$_{a}ruco_{d}etection.html$

[10] https://www.cognex.com/products/machine-vision/vision-software/vision-tools/pattern-matching/patmax-object-location?rdr=lgcy

of the older adults were reluctant to bring their grandchildren, as they needed to get the parents' permission, and some had grandchildren living far away. One way to support recruitment in the future is to ask the grandparent participating in the study to pass on the flyers to friends with grandchildren who might be able to participate.

3.5 Discussion

Intergenerational interactions between grandparents and grandchildren can support the well-being of both generations (see 2.1 for more details). Each dyad of grandparent-grandchild is different and needs to be supported in a way that makes sense to both members if the robot-mediated game is to work. Even in the same dyad, the players might have a different attention span and needs. This research recommends an iterative game design approach with this demographic because it helps researchers to justify their design choices and also to validate their early design. This finding aligns with previous research [47, 16, 18]. To the author's knowledge, this thesis research is the first attempt to use an iterative design approach in an HRI study to support intergenerational interaction between grandparent and grandchild. In contrast to many other HRI studies, this study does not have the robot as the main focus in interactions, but rather the robot is used as a tool to mediate the human-human interaction. This approach may be of value to other researchers in the HRI community.

In Stage 1 of the study, the dyads' ratings of perceived collaboration (see Figure 3.4) show that the Tangram game, along with the game setup, appears to have worked well for supporting collaboration in the intergenerational gameplay between grandparent and grandchild. However, this could also be influenced by their experience of playing games together; namely, Moore et al.'s research shows that familiarity with a teammate's attitudes can improve the team's performance and accuracy in a Virtual Reality (VR) collaborative task [55].

The dyads' responses on the envisioned role of Pepper suggest that having the robot to help them in the gameplay aligns with what they expect and would want the robot to do (see Section 3.2.6). This result aligns with the role of the robot in [9, 53], where the robot helped the player by providing clues to solve the Tangram puzzle. All the dyads wanted the robot to be present for the next Stages (see the Section 3.2.6), but this might be due to the novelty of interacting with Pepper. Since the study design involves two more sessions with the robot, the novelty effect might wear off with exposure. To explore the novelty effect, the plan was to recruit a minimum of three new dyads who would participate only in Stage 3, and compare their perceptions to the non-naive participants. Unfortunately, COVID restrictions curtailed our activities and this question remains for future research.

Although Stages 2 and 3 were not conducted, this chapter reports the design and development of Stage 2 and the theoretical design and protocol towards increasing the robot's autonomy for Stage 3. In addition, this chapter discusses challenges and possible ways to address them. The research outlined in this chapter can serve as a solid basis for putting together and executing Stages 2 and 3 in the future.

3.6 Chapter summary

The key contribution of this chapter is the multi-stage study design of a robot-mediated intergenerational gameplay. Results from the Stage 1 study showed that the game setup and the Tangram game appeared to be a good way to support enjoyable collaboration in grandparent-grandchild gameplay. This chapter also describes the design and development for Stages 2 and 3 of the study, as well as challenges in developing this intervention. To the best of the author's knowledge, this is the first robot-mediated intergenerational game designed for grandparents and grandchildren.

Chapter 4

Human-Robot Interaction Game Canvas (HRIGC)

While designing the multi-stage study for a robot-mediated intergenerational game, the author observed that, given the interdisciplinary nature of HRI game design, there was no appropriate tool to systematically describe the system, particularly in a way that is able to be used by and describes knowledge from fields such as sociological game design, robotics and psychology. The second part of this thesis research involved the creation of the Human-Robot Interaction Game Canvas (HRIGC), which is a systematic tool to represent the key elements required for designing HRI game system that is intended to fill this gap. It is envisioned that the HRIGC can help researchers to map knowledge required for HRI game design, develop their study, give rise to new knowledge, and contribute to the HRI community. The development of the HRIGC is described in this chapter with the final representation of our canvas model is described in section 4.2.5.

4.1 Background

4.1.1 Iterative Methods used in visualizing the conceptual model

With an aim to create a framework for the HRI game system, the author started by reviewing ways to represent the model. Giordanol et al. [26] explored different ways to represent a complex system, including:

- **Metaphor** is used to understand a complex system using some available information.

- **Cognitive maps** is a free form and diverse visual representation of a person's mental model.
  - **Influence diagram** is a graphical representation of a model with interaction between its elements and is related to decision-trees.
- **Mind maps** is a limited tree structure with topics and sub-topics. However, there is no definition of their relationships.
- **Concept maps** is the elaborated version of the mind map, which has labelled and directed edges to show their relationships.
- **System design modeling** is a method to represent complex and dynamic systems [26].

The author also looked into different diagrams, including flowcharts, Fishbone, Venn diagram, spider diagram, Unified Modeling Language (UML) [1] etc. Based on all these representations, the author had several iterations of digital [2] and non-digital brainstorming sessions with the research team to propose this conceptual model.

4.1.2 Main components of intergenerational gameplay using social agents

To start the process, the intervention described in Chapter 3 was used as a case study to begin to explore. Figure 4.1 represents the three fundamental elements of the model. The fundamental elements of the intervention described in Chapter 3 is as follows: Game: Tangram; Participants: dyads of grandparent-grandchild; Social agent (An agent that interacts with other agents or humans in a social environment [61]): Pepper. This chapter describes the concepts behind each of these fundamental elements and their connection.

[1] https://en.wikipedia.org/wiki/Diagram
[2] https://miro.com/app/dashboard/

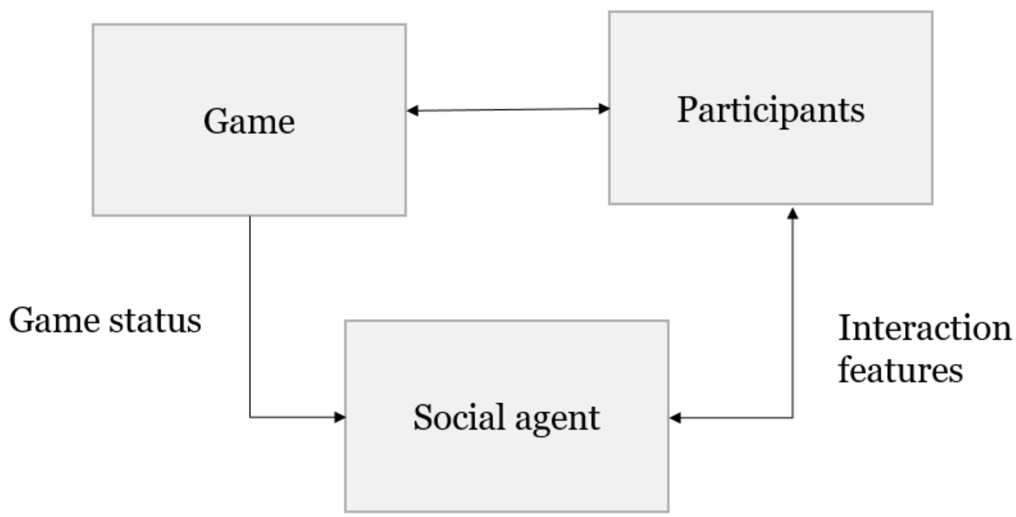

Figure 4.1: Three fundamental elements of the game system using a social agent.

The specific categories of the fundamental elements were chosen based on the literature and research goals.

- **Game**: Collaborative gameplay offers meaningful intergenerational interaction [67]. Tangram provides a collaborative space for the dyads. The Tangram game has been used in studies with older adults [54] and young children [9] and found suitable for both generations. The reason for choosing the game has been described in Section 2.2.3.

- **Players**: As the first research question of this thesis focuses on intergenerational interaction (see Section 1.1), the dyads of grandparent-grandchild were chosen as the game players.

- **Social agent**: Section 2.2.2 describes the reason for choosing the Pepper robot for this research.

Figure 4.2 shows the specific categories for each fundamental element. These categories are derived from the literature (see Sections 2.2.3 and 2.2.2) and the research goals (see Section 1.1.

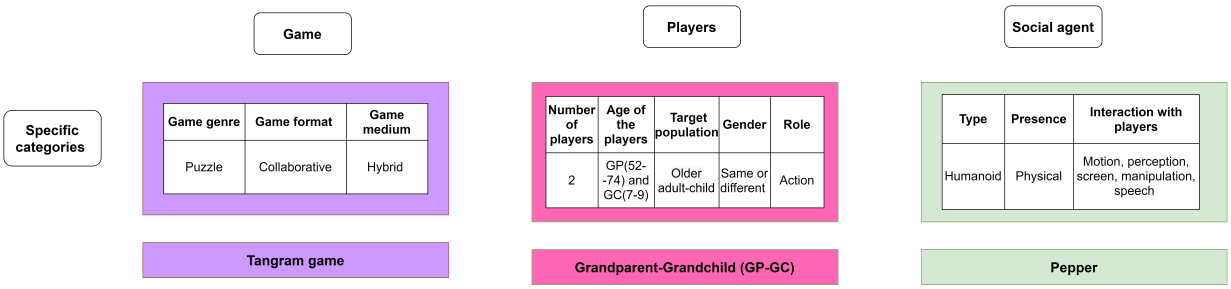

Figure 4.2: Specific categories of each fundamental element in game system using social agent based on the literature and research goals.

4.1.3 Existing models

Fundamentals of game design

Two frameworks were initially considered for describing the game design elements: 1) the Mechanics, Dynamics, and Aesthetics (MDA) framework [33]; and 2) The elemental tetrad model [75]. The MDA framework is intended to break down the game design into mechanics, dynamics, and aesthetics aspects and help researchers to understand how changes in one aspect impact the others. The elemental tetrad model helps to break down all the elements that form a game as mechanics, aesthetics, story and technology [75]. The elemental tetrad model was chosen over the MDA framework as it has 'Story' and 'Technology' elements which would help to better describe the HRI Game design.

The elemental tetrad model includes the following elements:

- **Mechanics** defines the procedure, rules, and goals of the game.
- **Aesthetics** gives the feel and look for the game. It depends on the preference of the participants. The mechanics and story are often modified based on aesthetics the participants prefer.
- **Technology** is the medium for aesthetics, mechanics, and story. It includes all materials and interactions needed in the game.
- **Story** is how the events are unfolded to the game. Mechanics should be chosen to strengthen and let the story emerge

It is important to consider all four elements of the tetrad model for designing any game, as each element affects the other elements. All four elements have equal importance for the success of the game. Dividing the game design elements into these four elements using the tetrad model would help the game design researcher study and improve each element. Technology elements are the least visible to the users, whereas aesthetics are the most visible [75].

Intergenerational activity system

Siyahhan et al. modified the activity theory system for intergenerational interaction [78]. Figure 4.3 shows the modified activity system of intergenerational gameplay [78].

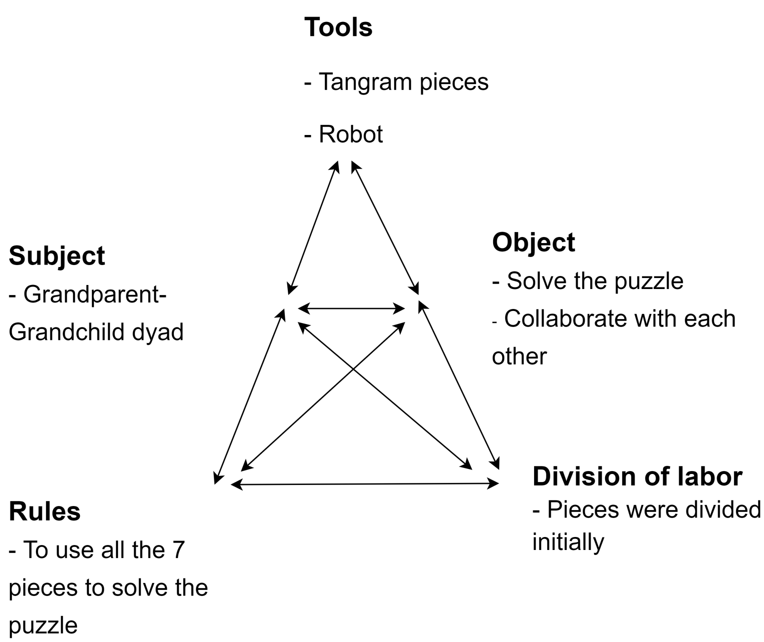

Figure 4.3: Activity system for robot-mediated intergenerational Tangram gameplay between grandparent and grandchild.

The author modified the activity system for intergenerational gameplay proposed by Siyahhan et al to adapt to an HRI game scenario [78]. The "Community" aspect of the model was removed, as it is quite uncommon in the HRI gameplay. The activity theory based model is considered an important tool for conceptual game design as it helps game designers to do an initial validation during the early design stage and hypothesize whether the game can achieve its intended goal [15].

Socialization style and behaviours

An insightful aspect of the intergenerational Tangram scenario is that the players are from different generations. This means there is an asymmetry in their interaction in terms of their cognitive ability, responsibility, investment in the game, focus, and goal-centered and emotional involvement [30]. This asymmetry leads to some specific socialization styles. A grandparent and grandchild can interact with each other in a shared activity, either using a democratic or authoritarian socialization style [87]. During a grandparent-grandchild interaction, the typical social behaviours observed are guidance, control (dominance) and affiliation [65].

Figure 4.4 represents the usual social styles and behaviours observed in grandparent-grandchild interaction in a shared activity. This Figure was created based on the psychology literature on intergenerational interaction [87, 65]. It is important to understand the natural interaction between the players so as to design a system that facilitates the collaboration between them.

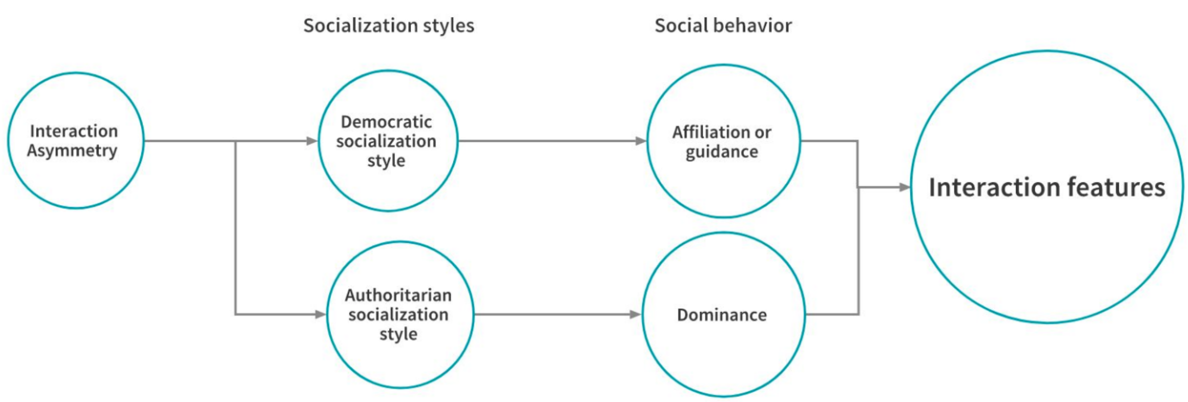

Figure 4.4: Common socialization styles and behaviours observed during an intergenerational interaction.

Interaction features

The interaction between a grandparent and grandchild produces social cues. Social cues can be either verbal or non-verbal. Non-verbal social cues include the face (face expression, eye gaze) and motion (body posture, gesture) [3]. In addition to that, the dyad's interaction in the game leads to specific game features, like the task completion rate and movement of pieces. These interaction features convey the state of interaction to the robot and is an important quantitative measure for researchers designing a game to foster collaboration. See the Sections 3.3.3 and 4.1.3 for more details on how these features are used and extracted by the researchers.

Computational elements

This sub-section includes the technological concepts that might be needed for intergenerationl HRI game design. HRI studies involving two players have used gaze (at the other player, at the task, at the robot), verbal communication between the players (social and task-oriented), and smile as an indication for collaboration among the players [90, 60, 92].

In dyadic interaction, researchers use OpenSMILE [4] to extract the audio features [34, 25]; CMU OpenPose library for body features [5] [34]; and Neural networks to extract eye features [25, 58]. One way to interpret social signals from more than one source in real time is by using the Social Signal Interpretation (SSI) Framework; this framework supports data from different sources and lets the researchers set up recognition pipelines based on their multi-modal input. This framework also has support for feature extraction algorithms and machine learning tools [36].

According to the definition of a robot by Maja J Matari´c,'A robot is an autonomous system which exists in the physical world, can sense its environment and can act on it to achieve some goals' [p.2, [51]]. Thus, a robotic system should have a goal and achieve its goal. In robot-mediated intergenerational Tangram gameplay, the goal of the system is to mediate the interaction within the dyad.

To promote long-term sustained interaction in a robot-mediated dyadic game, the robot should adapt its behaviour according to the collaboration between players.

[3] https://en.wikipedia.org/wiki/Social$_c ue$
[4] https://en.wikipedia.org/wiki/OpenSMILE
[5] https://github.com/CMU-Perceptual-Computing-Lab/openpose

Ritschel et al. used the SSI framework in an adaptation mechanism to make the robot adapt to the user's engagement, which was measured using social signals [70].

Interpreting social signals will let the robot know the state of the interaction. The robot would observe its state (environment), take an action, and receive a reward (positive, negative, neutral). The reward will let the robot know how good the taken action was, and, in the future, the robot will or will not choose the same action for a particular state [80, 70]. Q-learning, State Action Reward State Action (SARSA), Partially Observable Markov Decision Proces (POMDP) are the algorithms commonly used for decision-making in HRI [70, 27, 81]. Figure 4.5 conceptually represents the computational elements.

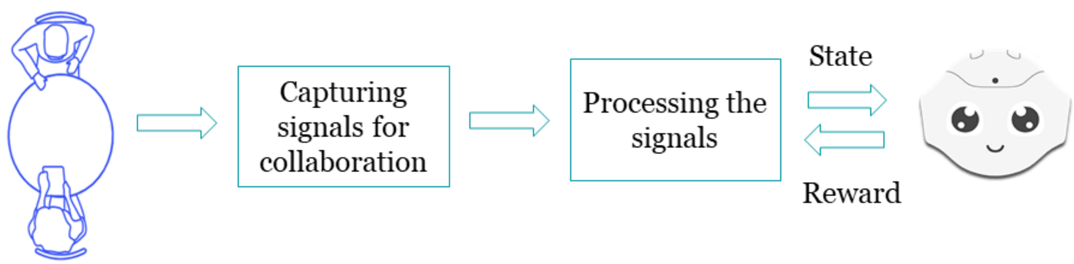

Figure 4.5: Conceptual representation of the adaptation mechanism for robot-mediated intergenerational Tangram game.

4.2 Development of the HRIGC

Figure 4.6 shows the steps taken in the development of HRIGC. Design of an HRI game system is multidisciplinary in nature. Hence, it is important to understand and get familiar with the key elements and state-of-the-art in domains relevant to HRI game design, including game design, HRI, and Psychology. The author started with a literature review; based on the literature, she had ten brainstorming sessions with the project research team to filter out the important aspects required for the HRI game system. After that, it took another ten brainstorming sessions for the author and her team to decide on canvas representation for the system. With the initial HRIGC, the author mapped the canvas with three case-study applications to see the applicability of the canvas. Based on the observations from the case studies, the author and her team developed the revised HRIGC. The author then engaged in a test-run with three HRI and four HCI researchers to create the final HRIGC. The final canvas representation is shown in Figure 4.14.

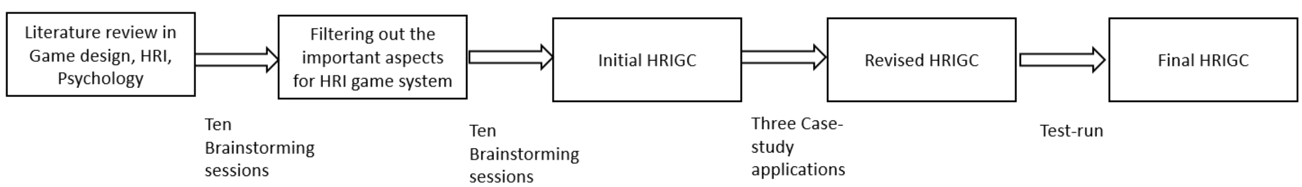

Figure 4.6: Steps involved in the development of HRIGC.

4.2.1 Creation of the initial version of the HRIGC

After the literature review and the filtering out of key aspects of the system with the research team, the author, guided by the team, explored different ways to represent an HRI game-based system (see Section 4.1.1 for details) and developed the following representations:

Layer representation of the system

The first approach to describing HRI gameplay was to create a high-level representation of the different components of an HRI gameplay system. Building on the ways to represent a complex system described in the literature (described section 4.1.1), and led by the author, the research team had two brainstorming sessions to create a layer representation of the HRI gameplay system. The layer representation was chosen because it is an intuitive representation of all the aspects. Figure 4.7 shows the resulting layer representation. This grounding, high-level representation of the HRI gameplay system guided the work described in the remainder of this chapter.

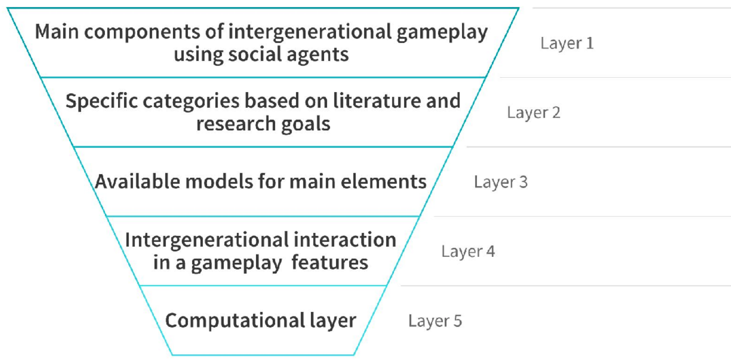

Figure 4.7: Layer representation model in which higher levels represent greater levels of specificity.

Intergenerational game design elements

Though the layer representation gave a high-level overview of the HRI game system, it lacked elements specific to the intergenerational interaction, which was the primary focus of this research. Costa et al. and Mahmud et al. suggested game design elements for older adults and children [18, 48], including thirteen recommendations that are closely related to the population and type of interaction targeted in this study. These recommendations include: 1) Social interaction; 2) Allowing Customization; 3) Appreciation of the Uncertainty; 4) Game contextualization; 5) Short and Asynchronous Play; 6) Peer-to-peer collaboration; 7) Role playing and real-life problems; 8) Interactive narratives; 8) Multimodal interaction; 9) Simple interfaces; 10) Passive play; 11) Digital component; 12) Player-centric approach.

These elements were analyzed in terms of the fundamental game design's four tetrad elements (i.e., Mechanics, Aesthetics, Technology, and Story; see Section 4.1.3 for more details) by mapping the recommended intergenerational elements to the four tetrad elements to understand how these recommendations fit the fundamental elements. This was done to see how the tetrad elements can describe the intergenerational game design recommendations; some intergenerational game design elements overlapped with more than one tetrad element.

Figure 4.8 shows the game design elements in our Tangram game and the associated Tetrad game elements. One brainstorming session was held to discuss how to represent the overlap clearly across the four fundamental elements, and author and her research team chose the Venn diagram representation.

The Tetrad game elements can also be adapted in HRI game design, as it would be easy for the researchers to analyze and improve each of the elements individually.

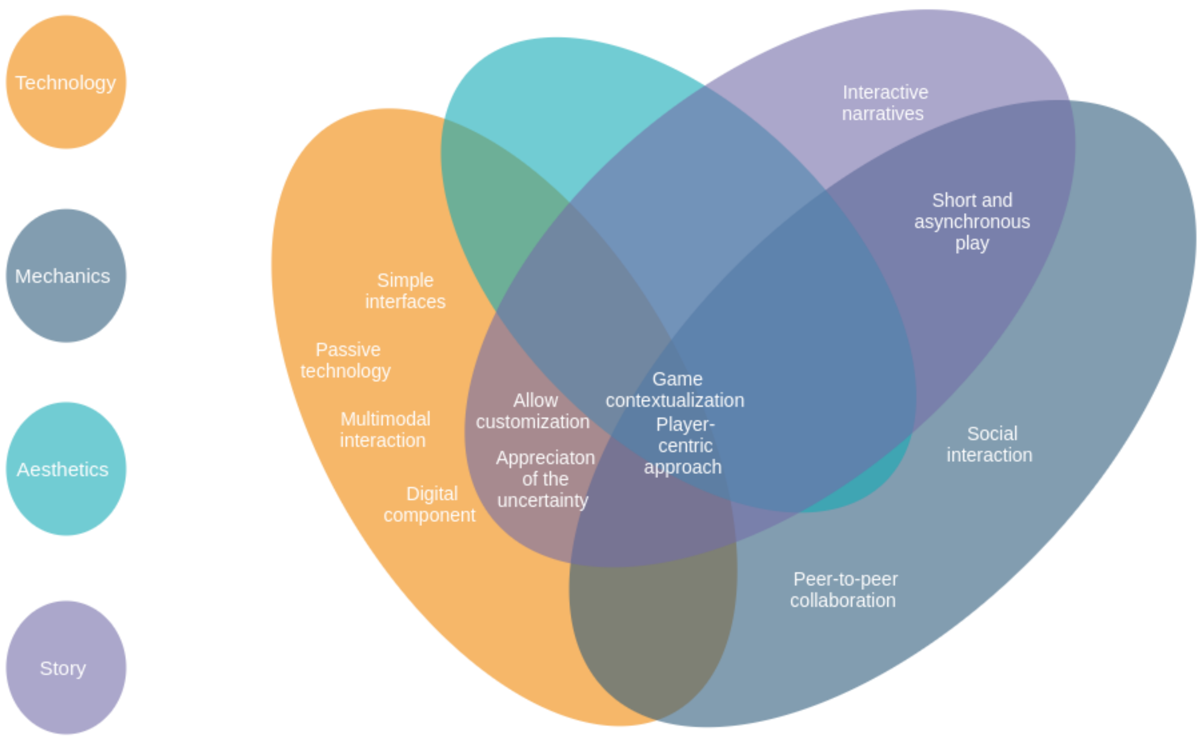

Figure 4.8: Venn diagram of game design elements and the associated Tetrad components.

Initial HRIGC representation

The author and her research team felt that aspects of the above two representations could be generalizable and applicable to other research. The initial version of HRIGC was created to describe in a cohesive manner the key aspects for the HRI game design, as is shown in Figure 4.9.

The structure of HRIGC is influenced by the Business Model Canvas (BMC), which is used to conceptualize business models (see the Section 2.3 for more details). The aim of the BMC corresponds with that of HRIGC, in that it provides a structured overview of a complex system; the HRIGC targets the field of HRI game design. The HRIGC describes the different aspects that are needed to be considered in HRI game design. With the important aspects from the background work (mentioned in Section 4.1) and with the layer and Venn representations (see Figures 4.7, 4.8), the author had five brainstorming sessions with the research team to create the initial version of the HRIGC (see Figure 4.9)

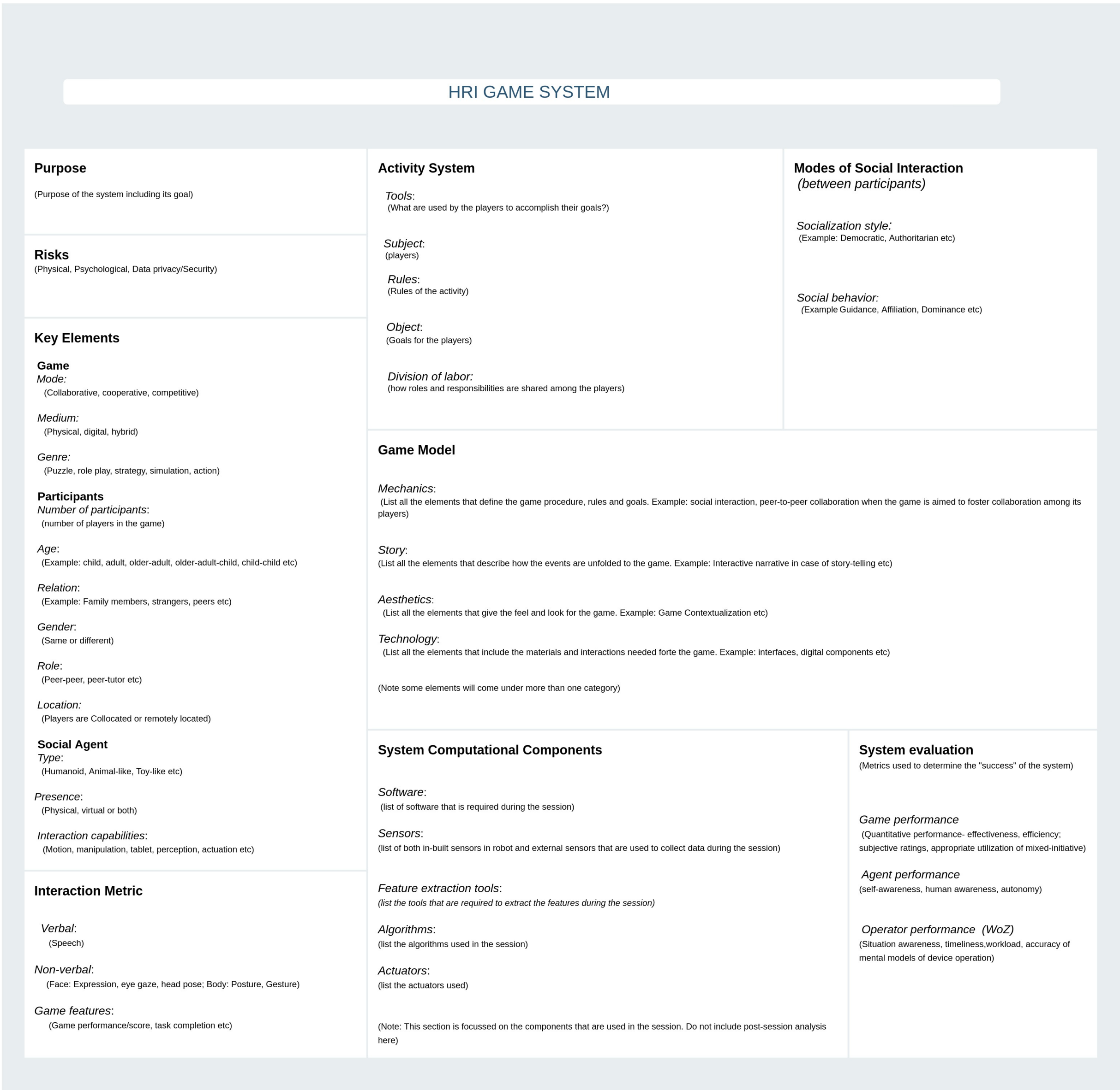

Figure 4.9: Initial HRIGC. Digital version can be found here.

The initial version of the canvas was evaluated by the author by completing it using three case studies: 1) Robots as social mediators in a remote human-human collaborative communication [60], 2) The effect of a robot's social character on children's task engagement [92], and 3) The robot-guided intervention described in Chapter

3. Based on observations by the author and research team, the initial canvas was modified to result in the revised version of the canvas presented in Figure 4.13.

4.2.2 Case study applications

To explore the generalization of the proposed canvas, three case studies were mapped to the canvas:

Case study 1: Robots as social mediators in a remote human-human collaborative communication [60]:

This paper explores how a robot can mediate remote human-human communication in a collaborative computer game. The authors used the AIBO robot with adult dyads connected via Skype. The player's goal is to navigate the virtual robot projected on the screen using a physical robot. This study has two conditions: (1) Conventional (without robot) mode, (2) robot mode. For the canvas, the robot mode was used.

Reasons to choose this paper as a case study are:

a) Dyadic HRI scenario involving game as a task

b) Robot role: Mediator

c) This paper focuses on mediating human-human communication rather than having the robot as a focus point.

Figure 4.10 shows the canvas representation for this study.

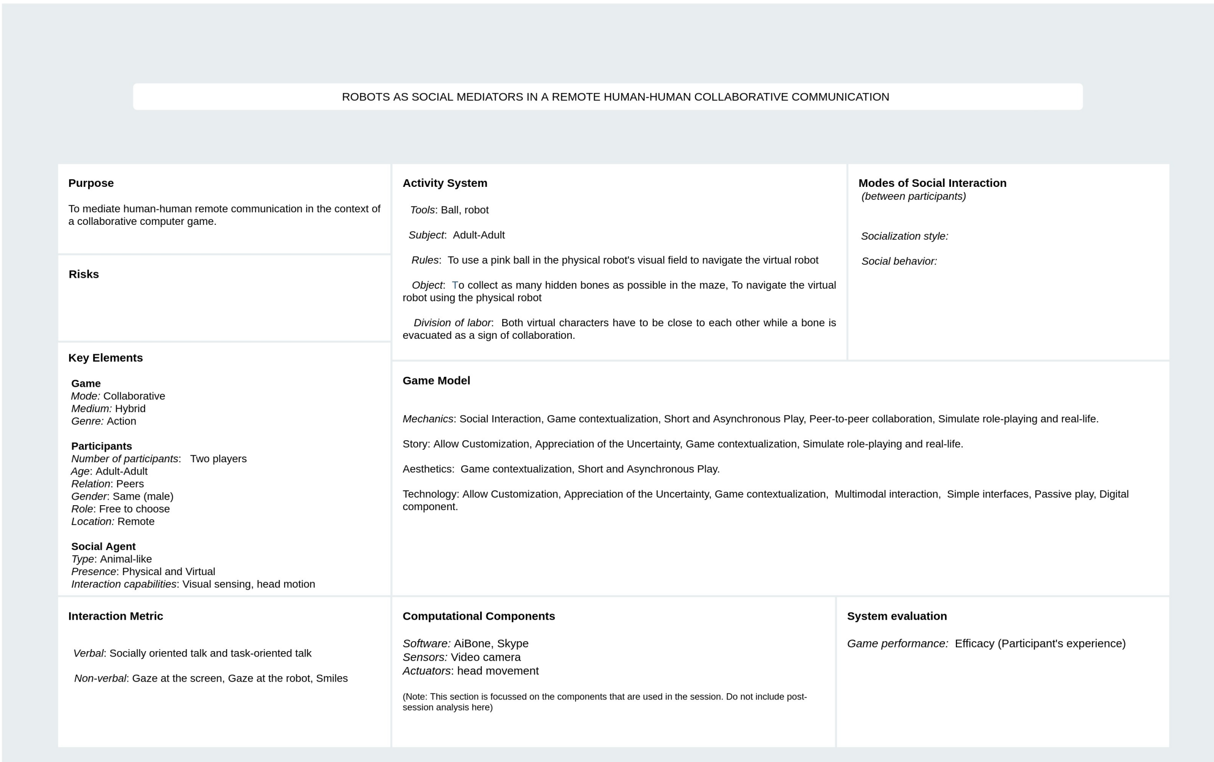

Figure 4.10: Case study 1: Robots as social mediators in a remote human-human collaborative communication. Digital copy available here.

Case study 2: The effect of a robot's social character on children's task engagement [92].

This paper analyses the effect of a social robot's character (Peer vs. Tutor) on children's engagement in a task. This study is conducted with dyadic children of the same age and gender. The dyads are asked to solve the Tangram game in three levels; the difficulty level increases with the increase in the game level. The results show that the interaction time was longer when the robot was in Peer mode compared to Tutor mode.

Reasons to choose this paper as a case study are:

a) Dyadic HRI scenario involving game as a task.

b) Uses the Tangram game.

Figure 4.11 shows the canvas representation for this study.

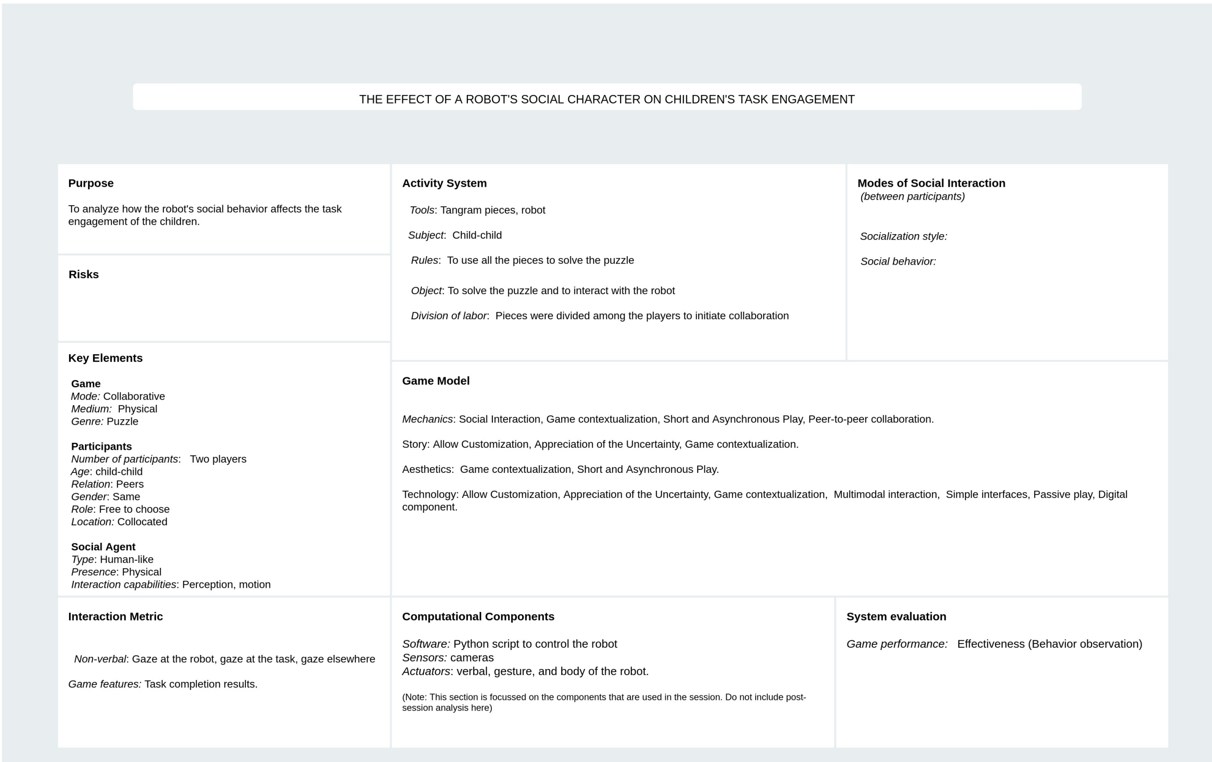

Figure 4.11: Case study 2: The effect of a robot's social character on children's task engagement. Digital version available here.

Case study 3: Robot mediated Intergenerational Tangram gameplay

This work has been described in Chapter 3 and the aspects for filling the canvas are discussed in Section 4.1.

Figure 4.12 is the canvas representation of our robot-mediated intergenerational Tangram system.

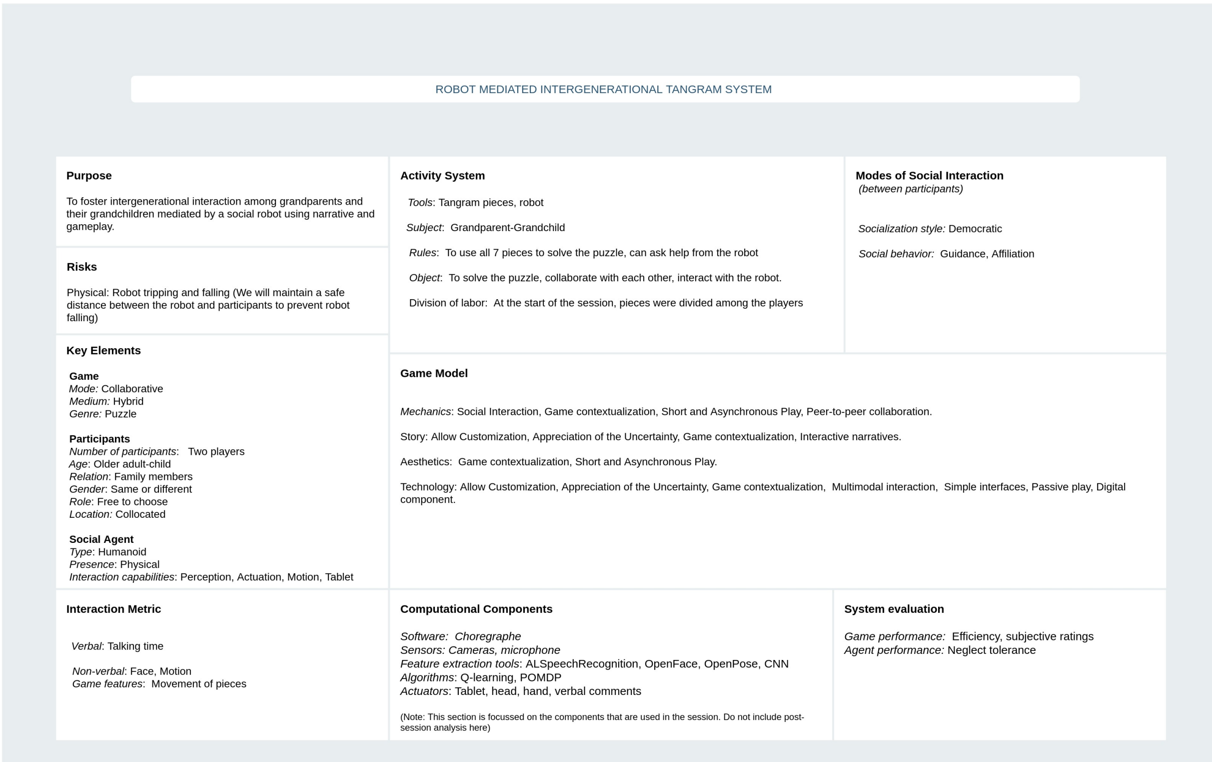

Figure 4.12: Intergeneraional Game system canvas. Digital copy of the canvas is available here.

4.2.3 Revised version of HRIGC

After filling out the initial version of HRIGC using the three case-study applications (see Section 4.2.2), the author had two brainstorming sessions with the research team to modify the initial canvas and develop the revised version of HRIGC shown in Figure 4.13. The observations and modifications from the case-study applications include:

1. In the initial HRIGC (see Figure 4.9), the purpose of the text in brackets below each aspect is to provide an intuition of what the aspect means. However, it was unclear whether these were examples or definite options. To clarify, the author added 'e.g.' only for the aspects that have examples and allowed the researchers to add to those examples.

2. All the elements except ‘Division of Labor’ in the ‘Activity System’ aspect in the initial HRIGC (Figure 4.9) overlap with the ‘Game Model’ and ‘Participants’ under ‘Key elements’ aspect. Thus, the ‘Activity System’ aspect was removed in the revised version of HRIGC in Figure 4.13.
3. ‘Gameplay considerations’ aspect was added in the revised version of HRIGC (Figure 4.13) and ‘Role’ under ‘Key elements’ aspect was moved to the ‘Gameplay considerations’ to group the ‘role of players’, ‘role of robot’, and the ‘division of labour’ together so that these elements can be clearly represented.
4. Case study 1 (Robots as social mediators in a remote human-human collaborative communication) and case study 3 (Robot-mediated Intergenerational Tangram gameplay) are aimed at improving the task engagement between human-human players and fostering collaboration between human-human players respectively. The Player Performance’ element was added in the ‘System Evaluation’ aspect.

Apart from these modifications, the author made aesthetic modifications, including increasing the font size, representing the aspects in bold and text below the aspect in italics, and other minor refinements to make the canvas more readable.

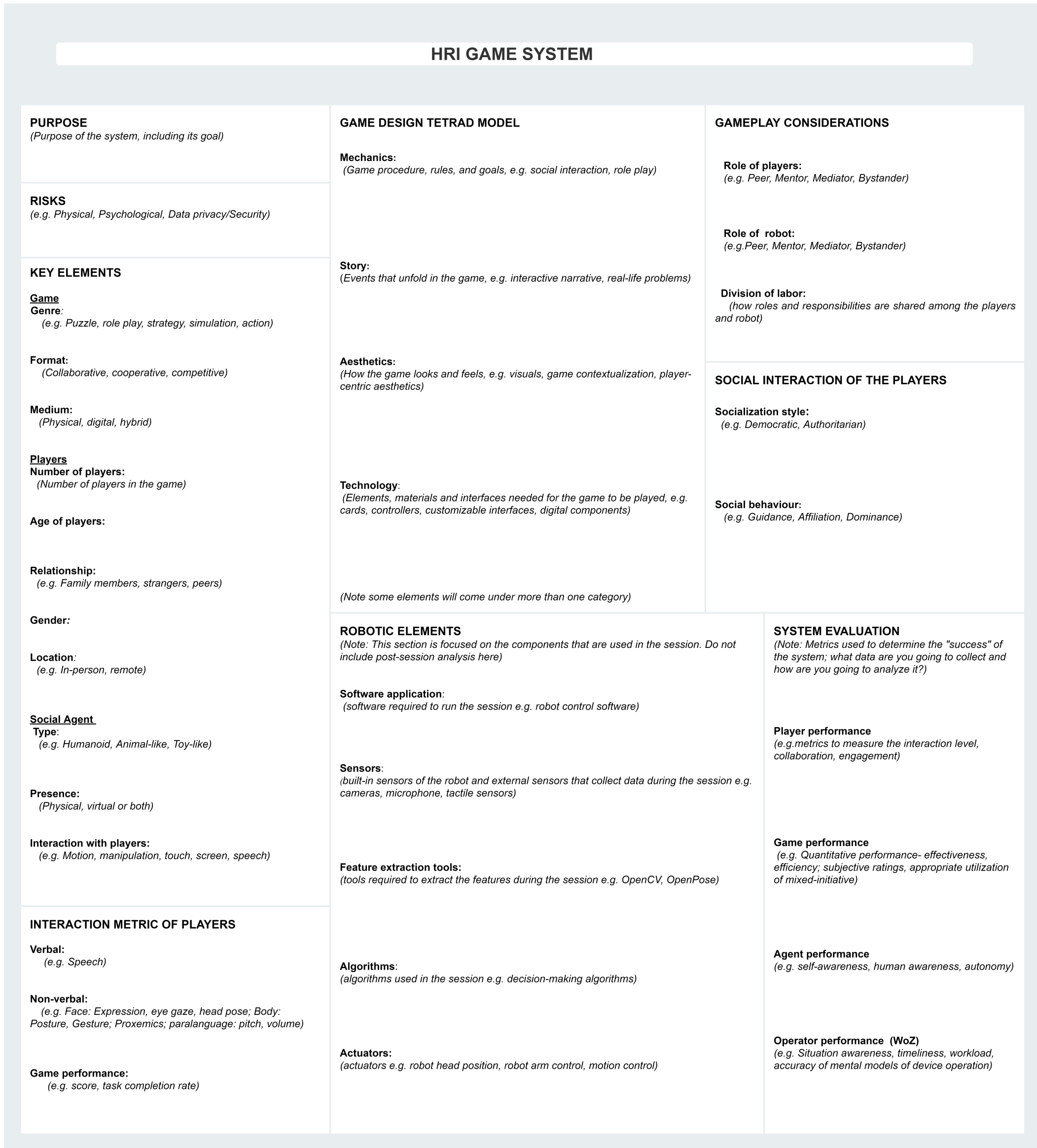

Figure 4.13: Revised HRIGC. Digital copy of the canvas is available here.

4.2.4 Test run

The revised version went through two test runs in an informal voluntary evaluation with researchers of related expertise:

Test run 1: Test run 1 included three researchers whose research involved game design using social agents. The researchers were asked to fill the canvas twice - once for their research and once using a case-study application [60]. Their feedback was collected by asking specific questions on a) Understandability; b) Missing aspects; c) Their suggestions for improvement. There were three respondents to the questions and the canvases were completed by two out of three respondents who volunteered for the Test run 1, seen in Appendix O and Appendix P.

A visual analysis was done with the canvases from Test run 1 to see whether the type of data respondents filled in the canvas aligned with the type of data expected. The following observations are made for the case-study application:

1. The researchers were describing things that were not explicitly described in the research paper. They seemed to have matched their understanding from reading the paper with the elements. Example: The 'Risks' and 'Social styles' were not described in the paper.
2. The 'Story' element of the 'Game Design Tetrad Model' did not match.
3. 'Division of labour' element seemed to be unclear as they mixed it either with the 'Role of robot' element or the 'Role of human' element.

Observations from the visual analysis for the canvases on the respondents' research include:

1) Researchers mixed up the 'Division of labour' element with the 'Role of human' element

2) For the 'Socialization style' and 'Social behaviour' elements, the respondents chose from the provided examples; it may not have been clear that that the description contained examples and not options.

The researchers' felt there were no missing elements in the canvas. For example, one researcher responded, "Template is pretty comprehensive", for the question " Is there any aspect you find missing,and you want it to be added to our template? If so, please list those."

In terms of understanding the canvas, one researcher responded, “ The agent performance section was not clear to me. But I missed reading the glossary which is why I had difficulty.”, and the other researcher’s response included, “Aesthetics section terms were not clear for me and I need to search for the terms; and Game performance was mentioned in two sections ‘Interaction metric of players’ and ‘System Evaluation’. Considering the latter response, the terminology was changed to ‘Game performance metric’ and ‘Game system performance’ in the ‘Interaction metric of the players’ and ‘System Evaluation’ aspects respectively.

Suggestions for improvement included: 1) Adding the Technology Readiness Level (TRL) to the canvas. 2) Including ‘user group’ instead of ‘gender’. 3) Explaining more on the ‘Aesthetics’ element in the glossary.

Test run 2: Test run 2 included four HCI researchers divided into two groups whose primary research backgrounds were:

Group 1: UX researcher and Controls system engineer

Group 2: Antenna design researcher and UX researcher

The researchers collaborated using the Miro tool [6]. The researchers were given the revised canvas and pre-populated movable text boxes containing the statements required to fill the canvas for a case-study application based on the paper [60]. There was one text box for each aspect canvas; for the aspects that were not described in the paper, the author chose to add examples in the text-box to determine their intuitiveness. Volunteers were asked to fill the canvas by placing one textbox in each aspect. After the canvas population activity, feedback was obtained by asking attendees to describe their thought process, in addition to an open-ended discussion with the author asking open-ended feedback questions related to intuitiveness and clarity. Examples include: a) Were you confused between any two or more elements? If so, what are they?, b) What are your suggestions for improving the canvas and why do you think so?. The canvases generated by the two groups can be found in Appendix Q.

For the first question, Group 1 pointed out that ‘Game performance’ is present in both ‘Interaction Metric of the Players’ and in ‘System Evaluation’ aspects. Though they can understand the difference of the elements under each of the aspects, it could be misleading; Group 2 reported no confusion among the elements in terms of the wording.

Some feedback from both groups on suggestions for improving the canvas included:

[6] https://miro.com/app/dashboard/

1. To make the canvas colourful.
2. 'Mechanics' and 'Story' elements of 'Game Design Tetrad model' were confusing. Adding more description for these elements could help to clear things.

A visual analysis was done with the canvases from Test run 2 to see whether the populated canvas aligned with the expected canvas (i.e., whether the aspects were filled with the appropriate text-boxes). From this,
Group 1 might have been confused between the 'verbal' and 'non-verbal' elements of the 'Interaction Metric of the Players' aspect with the 'Social behaviour' element in the 'Social Interaction of the Players' aspect. There was also interchange between the elements within the 'System Evaluation' aspect.
Group 2 was able to match all the elements, except for placing the 'Technology' element under the 'Mechanics' element for the 'Game Design Tetrad Model' aspect.

From the Test run 2 session, the author observed that both the groups were able to figure out all the elements of the 'Key Elements', 'Robotic Elements' aspects; 'Role of Players' and 'Role of Robot' elements of the 'Gameplay Considerations' aspect.

Based on the feedback from both test runs, the HRIGC was modified to make it more comprehensive and understandable. The key modifications include:

1. Better description for the 'Division of labour' element in the canvas.
2. More explanation on the Tetrad elements in the glossary.
3. Changed the wording to 'Gameplay metrics' and 'Game system performance' in the 'Interaction Metric of Players' and 'System Evaluation' aspects respectively.
4. Included 'Target Population' element under the 'Key Elements' aspects.
5. The visual analysis and response from researchers in Test run 1 showed that the researchers attempted to start filling the canvas without looking at the glossary. Adding a note on example and options might help, even when they don't use the glossary.

4.2.5 Final canvas version

Based on the test-run results (see the Section 4.2.4), the revised version of the canvas was modified to create the final version of HRIGC in Figure 4.14.

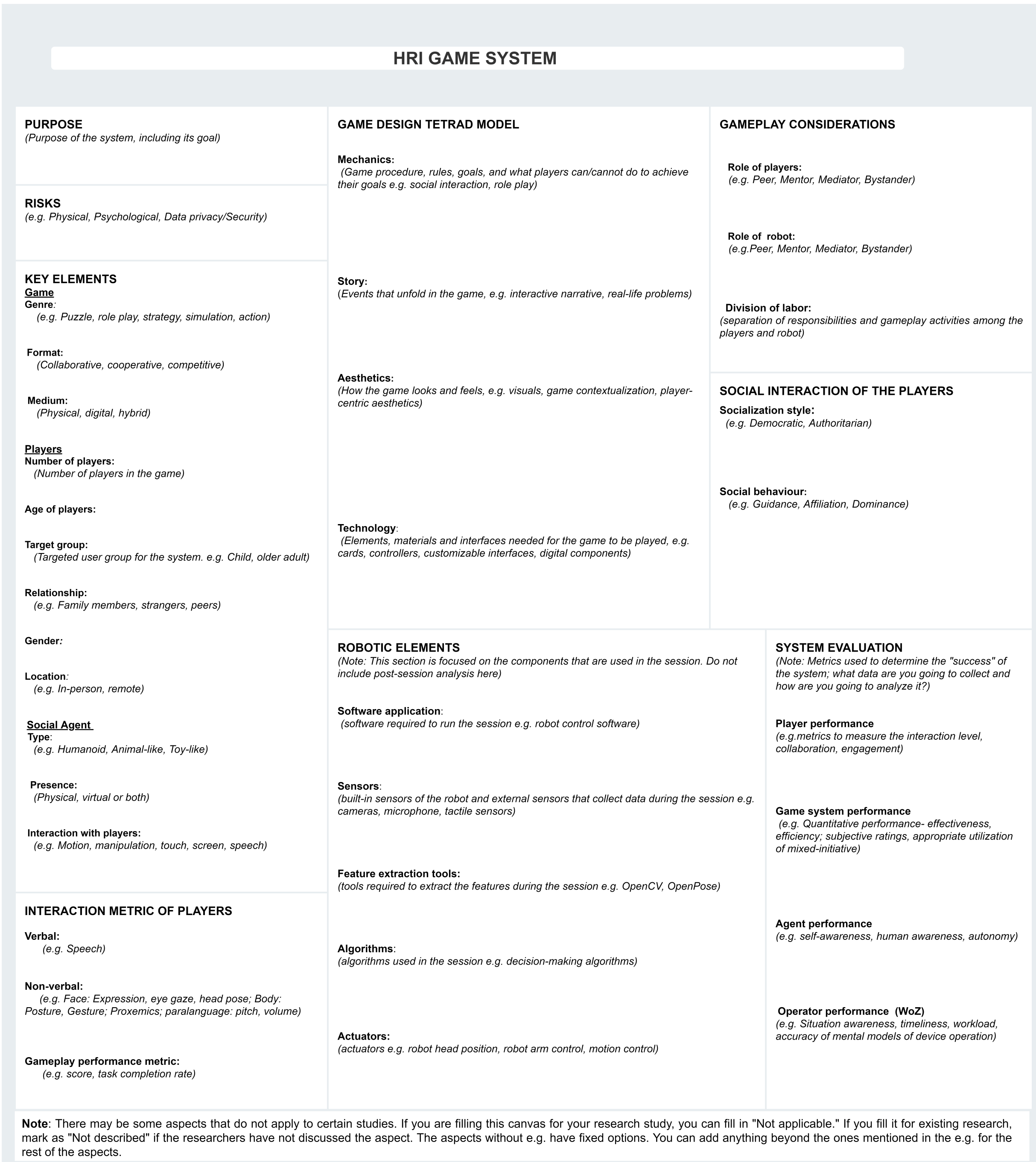

Figure 4.14: Final version of HRI Game canvas (HRIGC). Digital version of the canvas is available here.

4.3 Description of the canvas

Figure 4.14 is the final version of the canvas template for an HRI system involving gameplay. This canvas outlines nine aspects that should be considered while designing games with social agents. There may be some aspects that do not apply to certain studies. If a researcher is filling out the canvas for a study in which the researcher is engaged, then the researcher would fill in "Not applicable.", whereas for a researcher filling out the canvas for existing research,. the aspect would be marked as "Not described." The aspects without e.g. have fixed options. For the rest of the aspects, researchers can add beyond the ones mentioned in the 'e.g.' examples. The nine aspects are as follows:

4.3.1 Purpose

Purpose describes the motivation of the system, including its goal.
Example: To foster intergenerational interaction between grandparents and grandchildren mediated by a social robot using narrative and gameplay.

4.3.2 Risks

Include the negative consequence of any level caused by any task or material in the study.
Example: Physical, Psychological, Data privacy and Security risks, among others.

4.3.3 Key elements

- Game
  - **Genre**
    A category of a game is characterized by similar forms, such as the way in which the players interact in the game.
    Example: puzzle, role play, strategy, simulation, action.
  - **Format**
    The feature of the game that describes how the players interact with it.
    Example: collaborative, cooperative, or competitive.

  - **Medium**
    Channel in which the players play the game.
    Example: digital, physical, or hybrid.

- Participants
  - **Number of participants**
    Number of players play the game together.
  - **Age** of the players.
  - **Target population**
    The targeted user group for the system.
    Example: older adult and children
  - **Relationship**
    The relationship between the players can affect the way they interact with each other in the game. Example: family members, peers, strangers.
  - **Gender** of the players.
  - **Location**
    The position of the player concerning the other players. Example: In person, remote.

- Social agents
  - **Type**
    The category of the social agent based on its appearance.
    Example: humanoid (human-like), animal-like, toy-like.
  - **Presence**
    Presence of the agent in the game.
    Example: physical, virtual, or both.
  - **Interaction with players**
    This refers to the modalities used by the agent to interact with the players.
    Example: Motion, manipulation, touch, screen, speech.

4.3.4 Interaction metric of players

This includes the metrics that are measured during the interaction.

- **Verbal**
  Oral communication between the players.
  Example: Speech

- **Non-Verbal**
  It refers to the use of non-verbal channels to communicate.
  Example: face (expression, eye gaze, head pose); body (posture, gesture); proxemics; paralanguage (pitch, volume)
- **Gameplay performance metrics**
  Quantitative indicator for the "success" of the game
  . Example: game score, task completion rate.

4.3.5 Game design Tetrad model

- **Mechanics**
  The elements that define the game procedure, rules, and goals. Also includes what the players can and cannot do to achieve their goals and what will happen if players do something in the game
  Example: social interaction, role play. In the intergenerational tangram HRI system, the mechanics of the system include, 1) use all the seven pieces to solve the puzzle (rule); 2) can ask robot for help and break during the game (what players can do).
- **Story**
  Elements that describe how the events are unfolded to the game. They can be both linear and branching. All games don't necessarily need to have a story. Games can be abstract as well.
  Example: Interactive narrative, real-life problems. For the intergenerational tangram HRI system, the robot will narrate a story and give a puzzle in between and the story will continue when players complete the puzzle as an example for the story aspect.
- **Aesthetics**
  The elements responsible for how the game looks and feels to the players.
  Example: Visuals, game contextualization, player-centric aesthetics.
- **Technology**
  Comprises all the elements, materials, and interfaces needed for the game to be played.
  Example: cards, controllers, customizable interfaces, digital components.

4.3.6 Gameplay Considerations

- **Role of players**
  The function each player will assume in the game.
  Example: Peer, Mentor, Mediator, Bystander.
- **Role of social agent**
  The function the social agent will perform in the game.
  Example: Peer, Mentor, Mediator, Bystander.
- **Division of labour**
  The separation of responsibilities among/between the players and the social agent. Division of gameplay activities among/between players and the social agent.
  Example: one player uses a keyboard, and the other uses a mouse.

4.3.7 Social interaction of the players

- **Socialization style**
  Refers to the social practice the system expects/ promotes the players to interact with the other player.
  Example: Authoritarian, Democratic.
- **Social behaviour**
  Includes the behaviour system expected from the players during the interaction.
  Example: Guidance, Affiliation, Dominance.

4.3.8 Robotic elements

- **Software**
  Include the list of software required to run the session.
  Example: robot control software.
- **Sensors**
  Include the robot's built-in sensors and the external sensors required to collect the data during the session.
  Example: Cameras, microphone, tactile sensors.
- **Feature extraction tools**
  Refer to the tools by which the sensor data is extracted during the session.
  Example: OpenCV, OpenPose.

- **Algorithms**
  A set of computer-implementable instructions required to process the extracted features.
  Example: Machine learning algorithms, decision-making algorithms.
- **Actuators**
  Constitute the components responsible for the movement and control of the robot.
  Example: motion control, robot arm control, motion control.

4.3.9 System Evaluation

System Evaluation incorporates the elements that determine the success of the system. It includes what data will be collected and how it will be analyzed.

- **Player performance**
  Includes the metrics that determine how the players perform in the game.
  Example: interaction level, collaboration, engagement.
- **Game system performance**
  Evaluates the performance of the human-robot team.
  Example: Quantitative performance- effectiveness, efficiency, Subjective rating, Appropriate utilization of mixed-initiative.
- **Agent performance**
  Includes the metrics used to measure how well the agent performs its task in the session.
  Example: Self, awareness, human awareness, and autonomy.
- **Operator performance**
  Determines the performance of the operator (researcher controlling the robot). It is mostly used in cases where the robot is not fully autonomous.
  Example: Situation awareness, workload, and the accuracy of mental models of device operation.

4.4 Discussion

The goal of the HRIGC is to serve as a medium for researchers to identify, articulate, and consider different aspects and connections related to HRI gameplay applications.

To the best of the author's knowledge, the HRIGC is the first attempt to develop a standard tool to support the conceptualization of HRI game design. HRI game design is a diverse field with established methodologies of its own; the goal of the HRIGC is to serve as a roadmap for researchers to envision and describe their design process in a way that complements other established HRI techniques and methods. This approach aligns with that of Nagle et al., who created a canvas for supporting design research for data practitioners, where the authors noticed that their canvas complemented the frameworks of other researchers in the field to deepen understanding and convey key ideas [6].

The primary reason for developing the HRIGC is to support researchers in game-based HRI in thinking about and planning how to handle different characteristics of design, development, and evaluation. The test runs done in this thesis research indicate that the respondents could describe their research as well as the research in the case study application using the revised version of HRIGC (see Test run 1 in Section 4.2.4). In the visual analysis of the canvases filled out by respondents for the case-study application, all the elements aligned with those in the case study, except for the 'Story' and 'Division of labour' elements; the description of these elements was modified in the final HRIGC (see Figure 4.14) and in the glossary (see the Section 4.3). The respondents' responses regarding the understandability (see Test-run 1 in Section 4.2.4) of the revised canvas showed that they did not have difficulty, except for the 'Aesthetics' element when the glossary was provided. While the researchers' feedback suggests that the canvas is self-explanatory, the test run was done with only three HRI and four HCI researchers and is therefore preliminary.

In filling out the initial HRIGC for the three case studies, the canvas appears to be able to capture key aspects of HRI game design, including the purpose, key elements, metrics used, system evaluation methods, and other aspects. A side-by-side comparison of the completed canvases showed that these data could be quickly identified and compared. Thus, HRIGC shows promise as a tool for researchers to compare, contrast, and understand their research in a structured way; this could be done with existing completed research or research that is in development. In this way, descriptive information might be extracted, documented, and communicated more easily between researchers and other stakeholders. The use of the HRIGC to objectively compare research might be used to analyze different approaches to similar problems, which could then help researchers identify what might work for their particular application. The HRIGC might also be used as a communicative tool to present and discuss ideas related to HRI game design amongst multiple stakeholders. However, the author did not include this in the research, so it remains a future direction.

The author came across some challenges while creating the HRIGC. First, the multidisciplinary nature of HRI game design requires expertise from different domains, including game design, psychology, robotics, and other related stakeholder groups; therefore, these should be incorporated into, and can be captured by, the HRIGC. The author searched the literature from different domains and collaborated with a research team of game design and HRI experts to create the canvas. One aspect that was particularly challenging was the selection of the terminology to be used. The terminology is often different in each field, and there were instances where the literature and team members had different ways to say the same thing. For example, the same elements from the intergenerational activity system, from Learning Sciences and Psychology (see Section 4.1.3) and the game design tetrad model, from game design research (see Section 4.1.3) use different terminology that conveys similar information. 'Tools' in the activity system can be represented by 'Technology' in the game tetrad model. This made it hard to agree on which terminology to use. The selection of terminology is important, as it should be intuitive for all the different disciplines that may want to use the canvas. To make sure the person completing the canvas understands each element, the canvas included a short description and example for each element, as well as a description in the glossary (see Section 4.3). Responses from the test-run respondents show that they did not have difficulty in terms of how the elements were worded, except for the repetition of 'Game performance'. While the test run was performed with researchers from different backgrounds, it included a small sample size (n=7) and all had an engineering background. In the future, the canvas needs to be tested with a larger sample size and researchers from different fields to ensure that the terminology and glossary are intuitive.

Another challenge in creating the HRIGC was attempting to avoid domain bias. As the canvas covers different domains, such as HRI, game design, and Psychology, it was challenging to ensure the canvas captured key elements from domains so as not to prioritise one over the other. For example, for the intervention in Chapter 3 used as a starting point towards creating the HRIGC, the author came across the mechanisms that adult-child could use to interact with each other, like Motherese, Social referencing, and scaffolding and its HRI applications to enhance the emotional intelligence of the robot [46, 13, 72]. The author and the research team decided not to include these mechanisms, as this would bias the canvas toward the adult-child interaction. Rather, different methods like self-assessment, interviews, psychophysiology, task performance, and observations can be used to evaluate an HRI study [10]. The elements in the 'System Evaluation' aspect was carefully chosen to be inclusive for the HRI game system and not biased towards the HRI system; diversity of the players could lead to asymmetry in game play experience, specifically in terms of mechanics, dynamics and aesthetics. The game should be designed to consider the diversity of the players and use this as a tool to enhance the game experience. Including specific elements related to the asymmetry for mechanics, dynamics, and aesthetics would have made the canvas biased on game designing. The author and the research team decided to leave it open-ended for the researchers to include the elements that they find important to their study under each aspect of the canvas. During the ten brainstorming sessions of the author and research team, elements were curated, organised, and presented in a way that attempted to avoid bias towards one specific domain. From the test-run results (see Section 4.2.4), there was only one suggestion to modify an element (i.e., use of term "user group" instead of "gender"), one suggestion to add a technology readiness level element, and no suggestions to remove elements. This suggests the researchers in the test-run group felt the canvas was representative of their domain knowledge; however, to confirm this the canvas will need to be tested in future research.

Making the canvas comprehensive and cohesive was another challenge, as it needs to incorporate all the important aspects, while fitting into a paper-sized format. Since the canvas has limited space, the aspects and terminology were chosen so that the canvas is not overpopulated, but still conveys the necessary information. The author also included a short description of each element in the canvas,along with options and examples.

The nature of conceptual modelling is very iterative and collaborative [64]. It needs several iterations and brainstorming sessions with HRI game system representation. After trying out the many ways to represent our complex system (see Section 4.1.1), the team developed the layer (Figure 4.7), Venn (Figure 4.8), canvas representations (Figure 4.14). It was challenging to collaborate digitally as a result of COVID-19 pandemic constraints; however, the research team used digital collaborative tools like Miro [7] and video conferencing. The methods used in the development process of the canvas might interest researchers focusing on system modelling.

[7] https://miro.com/app/dashboard/

4.5 Chapter Summary

This chapter puts forward the background and development process involved in creating the HRIGC. The initial HRIGC was tested on three case-study applications and modified to reflect changes identified through that exercise. The revised version was then test run with seven researchers and results used to create the final version.

The key contribution of this work is the development of HRIGC. HRIGC is intended to be used by the researchers in HRI game design in general (not only for the robot-mediated intergenerational gameplay) to conceptualize a HRI game system. The HRIGC has been created in response to the lack of a systematic tool in capturing the different characteristics of HRI game design. The intentions if for the HRIGC to be used in several ways, such as: 1) a starting point for a researcher to think about and understand the characteristics of game design with social agents; 2) to compare characteristics between different interventions; and/or 3) examine existing research to identify, compare, and contrast approaches to different elements. The case studies and test runs of the HRIGC suggest it is working; however, testing with a large number of applications and researchers is required in the future to fully validate it.

Chapter 5

Conclusion

5.1 Summary

This thesis explores the following research questions:

How might a robot-mediated game be used to foster intergenerational gameplay?

The three stages designed to mediate the intergenerational interaction within the dyad of grandparent and grandchild using a social robot are: 1) Human mediator; 2) Pepper robot in WoZ; 3) Pepper in Semi/fully autonomous mode. To create a collaborative gameplay that is suitable to be played by a grandparent and grandchild, a puzzle game called Tangram was chosen. The Stage 1 study was conducted with four dyads of grandparents (52-74 years of age) and their grandchildren (7-9 years of age). Results from Stage 1 showed that the Tangram game and the study setup worked well for collaboration, and the dyads envisioned the robot as providing help in the gameplay. The design of Stage 2 was built upon these insights. Though Stage 2 was designed and developed, the research could not be completed, due to the suspension of in-person research in response to the COVID pandemic. The design and the development of Stages 2 and 3, along with the challenges faced during the process, is documented in this thesis.

What template can be created to conceptually describe HRI game systems?

The HRIGC was created as a systematic tool to conceptually represent game design that uses social agents. Robot-mediated intergenerational gameplay was used as a beginning point towards the exploration of key aspects needed for HRI game design. Key aspects were identified from HRI, game design, and Psychology literature and chosen through brainstorming sessions with the research team. Iterations and brainstorming sessions led to the initial HRIGC. Three case studies were used to evaluate the initial HRIGC. Observations from the case study validation led to the revised HRIGC. Further evaluation of the revised HRIGC was done through two test runs with a total of seven researchers. Based on this, the final version of HRIGC was created.

5.2 Contribution to knowledge

The key contributions of this thesis research are:

- The findings from the Stage 1 study show that the Tangram game and the study setup used in this research seem to work well for fostering grandparent-grandchild collaboration.
- The iterative design of a multi-stage study to foster interaction between grandparent and grandchild, mediated by the Pepper robot.
- Creation of the HRIGC, which is the first tool for systematically capturing the key aspects of an HRI game system.

5.3 Limitations

5.3.1 Multi-stage study design for robot-mediated intergenerational gameplay

The Stage 1 study was limited to the grandparent-grandchild demographic in the Waterloo region. In addition, the high levels of perceived collaboration and the preference to have robot presence for the next stages could affect the interaction of the robot with the players. To limit these potential biases, the dyads should be recruited from culturally diverse pool, which is a challenge as the study is designed to be conducted in the laboratory setup.

The grandparent-grandchild dyads who participated in this study were able to come to the study location together, having obtained the parents' permission for the participation of the grandchild. This could mean that the dyads have a better than average relationship with each other. This might have impacted the Stage 1 results on high perceived collaboration. In order to claim that the robot-mediated game fosters the interaction between grandparent and grandchild, it needs to be tested with different dynamics of relationships and in different settings, such as a long-term care setting, in which the grandparent and grandchild have a different type of relationship and/or do not meet often.

While a small sample size is mostly preferred for an iterative design approach, the sample size for the Stage 1 study is too small to generalize and significant claims cannot be made with the results from this research. The study needs to be expanded with a larger sample size in the future.

While Stage 2 and Stage 3 of the study were designed based on the Stage 1 results, literature, and collaboration with the HRI and game design experts, the proposed multi-stage study design is not validated as a result of the constraints imposed by the COVID-19 pandemic and this remains as future work.

5.3.2 HRIGC

The HRIGC is created to be used as a tool to aid researchers to think about the key aspects in the HRI game design. However, it might limit researchers from exploring other aspects. It needs to be clearly stated that the canvas only covers the key aspects and not all the aspects for HRI game design.

While the development process of the HRIGC included the background from multiple domains and involvement of domain experts, it is not formally validated. Hence, claims on canvas intuitiveness, comprehensiveness, and usefulness cannot be made. Thus, formal validations with a larger sample size are needed to support the usability of the canvas.

5.4 Future work

Multi-stage study design for robot-mediated intergenerational gameplay

The next step in robot-mediated research is the execution of Stage 2 and Stage 3 of the study once in-person research resumes. It is important to check and modify the design according to state-of-the-art approaches when the study is conducted.

Another interesting research aspect could be to study the impact of a robot's presence by comparing the dyads' interaction metrics with and without the presence of the robot. This has the potential to answer the question of suitability of robots in an intergenerational Tangram game by comparing the dyad's natural collaboration level with the collaboration level in the presence of the robot. This comparison would enable a better estimation of the efficacy of the robot intervention versus non-robotic gameplay.

HRIGC

Given the HRIGC is created with a small group of researchers from the same institution, it is important to formally validate with many more researchers with their own applications. Validation should specifically examine aspects such as the intuitiveness, inclusiveness of related domains, comprehensiveness, and potential applications.

Once the HRIGC is validated, it can be made digitally available for researchers to use. An open-access repository or database where researchers populated examples of their work using the elements of the canvas could enable the field to share and compare their approaches more quickly and easily.

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APPENDICES

Appendix A

Information Letter for Participants

INFORMATION LETTER FOR PARTICIPANTS

Project Title: Pepper: A mediator for intergenerational relationships

Team members:

Name	**Department**	**Role**	**E-mail addres**
Kerstin Dautenhahn	Electrical and Computer Engineering/Systems Design Engineering	Principal Investigator	kerstin.dautenhahn@ uwaterloo.ca
Jennifer Boger	Systems Design Engineering	Faculty supervisor	jboger@ uwaterloo.ca
John Munoz	Systems Design Engineering	Collaborator	john.munoz.hci@ uwaterloo.ca
Aishwarya Aravamuthan	Systems Design Engineering	Student Investigator	akaravam@ uwaterloo.ca
Katrin Fischer	Electrical and Computer Engineering	Research Assistant	katrin.fischer@ uwaterloo.ca
Shruti Chandra	Electrical and Computer Engineering	Collaborator	shruti.chandra@ uwaterloo.ca

Intergenerational interaction benefits all generations. Games are a good way to connect humans. The benefits of gameplay might even be enhanced through the use of technology. In this case, we are trying to understand how a robot would benefit collaboration.

You are invited to participate in a research study about a robot-mediated game for fostering intergenerational relationships.

Purpose of the Study: We would like to study how a robot can foster collaboration in an intergenerational game.

Participation criteria: Grandparents must participate with their grandchild.
Inclusion criteria for grandparents:

- Age doesn't matter, must have a grandchild (6-10 years) who can come to the study location.
- Must be able to travel to the study location.
- Should be able to understand and speak English.
- Normal to corrected vision.

Procedure: Should you choose to participate, you will be asked to sign a consent form. This is a multi-stage study and you will be asked to come to the University of Waterloo (E7 Building, The University of Waterloo, 200 University Avenue West,Waterloo, Ontario, Canada N2L 3G1) on three different days, each several weeks apart. Each time, you will be asked to play the Tangram game (introduction will be provided) with your grandchild. The game involves arranging shapes to solve puzzles. A robot will be present and will engage with you differently on each day. In all instances, the robot's behaviour will be non-threatening and it won't be touching you.

Session1: You and your grandchild will be introduced to and asked to play Tangram with a researcher present. You will also be introduced to a robot who will participate in the game in the next two visits of the study.

Session 2: You and your grandchild will be asked to play Tangram with the robot interacting with you during the game.

Session 3: You and your grandchild will be asked to play Tangram, again with a robot interacting with you, but the robot might exhibit a slightly different behavior this time.

All sessions will be videotaped. The purpose of videotaping is for post-study data analysis and the participant's identity will not be revealed when used in publications or presentations. (i.e. while your face is visible based on your consent, identifiable data such as names will be removed) .

Each session of the study will last for about 60-90 minutes.

Your rights as a participant: Your participation is voluntary; you are free to withdraw your participation at any time. If for any reason you feel uncomfortable taking part, please let the researcher know so that they can discuss and address your concerns. You can still always choose to withdraw from this study. You will receive prorated remuneration for the attended session in case you decide to withdraw.

Confidentiality: The data captured will be stored on a secure password-protected lab server with access only to the researchers. Your name will not appear in any report, presentation or publication resulting from this research. The file linking name and participant code will be kept for a minimum of 7 years, and only the researchers associated with this project will have access to it. Data will be de-identified (i.e. while your face is visible based on your consent, identifiable data such as names will be removed) when presented in academic publications. You can request your data be removed from the study up until Feb. 1, 2020, as it is not possible to withdraw data once publications have been submitted to publishers.

You will be provided with a feedback letter upon the completion of your participation, which explains what data we collected and how this ties in with our research questions. If you are interested and provide your contact information by email, you will also be provided with a copy of any scientific articles prepared for presentation or publication based on this study.

Remuneration:

Grandparent and grandchild will receive a gift card of 30$ each at the end of the third session as well as a photograph of both of them together with the robot in appreciation for their participation in the study.

Benefits of the study: You will not directly benefit from participation in this study. Participation in the study may be enjoyable to you and the study will benefit the research community.

Risks associated with participation: There could be a risk of the robot tripping/falling. We will make sure that a safe distance is maintained between you and the robot.
There might be a risk of psychological stress during the game during as you might not be used to being observed, despite the scenario being a game, designed to be enjoyable for you.
In case you have any signs of discomfort, frustration or evident emotional distress, during the session, researchers will ask you if they want to stop or pause the session. Moreover, participants will not be left unsupervised with the robot, researchers will be present at all times. The robot also features an emergency stop button in case all movements need to be stopped.

Contact Information: This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE# 40503). If you have questions for the Committee contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca.

For all other questions or any questions regarding participation in this study, please feel free to contact the student researcher.

Name: Aishwarya Aravamuthan
Email: akaravam@uwaterloo.ca

Appendix B

Information Letter for parents/Legal Guardian

University of Waterloo

INFORMATION SHEET FOR PARENT/LEGAL GUARDIAN

Project Title: Pepper: A mediator for intergenerational relationships

Team members:

Name	**Department**	**Role**	**E-mail addres**
Kerstin Dautenhahn	Electrical and Computer Engineering/Systems Design Engineering	Principal Investigator	kerstin.dautenhahn@ uwaterloo.ca
Jennifer Boger	Systems Design Engineering	Faculty supervisor	jboger@ uwaterloo.ca
John Munoz	Systems Design Engineering	Collaborator	john.munoz.hci@ uwaterloo.ca
Aishwarya Aravamuthan	Systems Design Engineering	Student Investigator	akaravam@ uwaterloo.ca
Katrin Fischer	Electrical and Computer Engineering	Research Assistant	katrin.fischer@ uwaterloo.ca
Shruti Chandra	Electrical and Computer Engineering	Collaborator	shruti.chandra@ uwaterloo.ca

Your child is invited to participate in a research study about a robot-mediated game for fostering intergenerational relationships.

Purpose of the Study: Intergenerational interaction benefits all generations. Games are a good way to connect humans. The benefits of gameplay might even be enhanced through the use of technology. In this case, we are trying to understand how a robot would benefit collaboration.

Participation criteria: Children (6-10) must participate with their grandparent.

Inclusion criteria for grandchild:

- Age between 6-10 years
- Should have a grandparent (age of grandparent doesn't matter)
- Grandparent must be able to travel to the study location.
- Should be able to understand and speak English.

Procedure: Should you choose to let your child participate, you will be asked to sign a consent form. This is a multi-stage study and your child will be asked to come to the University of Waterloo (E7 Building, University of Waterloo, 200 University Avenue West,Waterloo, Ontario, Canada N2L 3G1) on three different days, likely several weeks apart. Each time, your child will play the Tangram game (introduction will be provided) with their grandparent. The game involves arranging shapes to solve puzzles. Please note that while you are welcome to accompany your child to the study location, we ask that you wait outside of the lab during the session to minimize distractions.

Session 1: Your child along with their grandparent will play Tangram with a researcher present. Your child will also be introduced to a robot who will participate in the game in the next two visits of the study.

Session 2: Your child and their grandparent will be playing Tangram with a robot offering help during the game.

Session 3: Your child and their grandparent will be playing Tangram, again with a robot offering help, but the robot might exhibit a slightly different behavior this time. In all instances, the robot's behaviour will be non-threatening and it won't be touching your child.

The whole study will be videotaped. The purpose of videotaping is for post-study data analysis and the participant's identity will not be revealed when used in publications or presentations. (i.e. while your child's face is visible based on your consent, identifiable data such as names will be removed) .

Each session of the study will last for about 60-90 minutes.

Your child's rights as a participant: Your child's participation is voluntary; your child is free to withdraw their participation at any time. If for any reason you/your child feels uncomfortable taking part, please let the researcher know so that they can discuss and address your concerns. You can still always choose to withdraw from this study. Your child will receive prorated remuneration for the attended session in case you decide to withdraw.

Confidentiality: The data captured will be stored on a secure password-protected lab server with access only to the researchers. Your child's name will not appear in any report, presentation or publication resulting from this research. The file linking name and participant code will be kept for a minimum of 7 years, and only the researchers associated with this project will have access to it. Data will be de-identified (i.e. while your face is visible based on your consent, identifiable data such as names will be removed) when presented in academic publications. You can request your child's data be removed from the study up until Feb. 1, 2020, as it is not possible to withdraw data once publications have been submitted to publishers.

You will be provided with a feedback letter upon the completion of your child's participation, which explains what data we collected and how this ties in with our research questions. If you are interested and provide your contact information by email, you will also be provided with a copy of any scientific articles prepared for presentation or publication based on this study.

Remuneration:

Grandparent and grandchild will receive a gift card of 30$ each at the end of the third session as well as a photograph of both of them together with the robot in appreciation for their participation in the study.

Benefits of the study: Your child will not directly benefit from participation in this study. Participation in the study may be enjoyable to your child and the study will benefit the research community.

Risks associated with participation: There could be a risk of the robot tripping/falling. We will make sure that a safe distance is maintained between your child and the robot.
There might be a risk of psychological stress during the game during as your child might not be used to being observed, despite the scenario being a game, designed to be enjoyable for your child.In case your have any signs of discomfort, frustration or evident emotional distress, during the session, researchers will ask your child if they want to stop or pause the session.
Moreover, participants will not be left unsupervised with the robot, researchers will be present at all times. The robot also features an emergency stop button in case all movements need to be stopped.

Contact Information: This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee. If you have questions for the Committee contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca.

For all other questions or any questions regarding participation in this study, please feel free to contact the student researcher.

Name: Aishwarya Aravamuthan
Email: akaravam@uwaterloo.ca

Appendix C

Participants Consent form

University of Waterloo

CONSENT FORM FOR PARTICIPANTS

Project Title: Pepper: A mediator for intergenerational relationships

Team members:

Name	**Department**	**Role**	**E-mail address**
Kerstin Dautenhahn	Electrical and Computer Engineering/Systems Design Engineering	Principal Investigator	kerstin.dautenhahn@ uwaterloo.ca
Jennifer Boger	Systems Design Engineering	Faculty supervisor	jboger@ uwaterloo.ca
John Munoz	Systems Design Engineering	Collaborator	john.munoz.hci@ uwaterloo.ca
Aishwarya Aravamuthan	Systems Design Engineering	Student Investigator	akaravam@ uwaterloo.ca
Katrin Fischer	Electrical and Computer Engineering	Research Assistant	katrin.fischer@ uwaterloo.ca
Shruti Chandra	Electrical and Computer Engineering	Collaborator	shruti.chandra@ uwaterloo.ca

By signing this consent form, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

I have read the information presented in the information letter about a study being conducted by the research team as part of Aishwarya Aravamuthan's Master thesis led by Dr. Kerstin Dautenhahn and Dr Jennifer Boger from Systems Design Engineering at the University of Waterloo. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions and any additional details I wanted.

I am aware that I may withdraw my consent for any of the above statements or withdraw my study participation during the data collection phase of the study without penalty by advising the researcher.

All sessions will be videotaped. The purpose of videotaping is for post-study data analysis and the participant's identity will not be revealed when used in publications or presentations (i.e. while your face is visible based on your consent and identifiable data such as names will be removed).

This study has been reviewed and received ethics clearance through University of Waterloo Research Ethics Committee. If you have questions for the Committee contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca.

Participant Name: ____
(Please print)

Participant Signature: ____________________________________

Witness Name: ____
(Please print)

Witness Signature: _______________________________________

Date: ____

Data use in future research
Additionally, I consent for data collected in this study to be used in future research. My consent / non-consent to the future use of data does not impact my participation in this study.

_______ I consent for my data to be used in future studies.
_______ I **DO NOT** consent for my data to be used in future studies.

_______ I consent using the video and pictures collected in the study to be used in academic publications and presentations.

_______ I **DO NOT** consent using the video and pictures collected in the study to be used in academic publications and presentations.

Appendix D

Parents/Legal Guardian Consent form

CONSENT FORM FOR PARENT/GUARDIAN

Project Title: Pepper: A mediator for intergenerational relationships

Team members:

Name	Department	Role	E-mail address
Kerstin Dautenhahn	Electrical and Computer Engineering/Systems Design Engineering	Principal Investigator	kerstin.dautenhahn@ uwaterloo.ca
Jennifer Boger	Systems Design Engineering	Faculty Supervisor	jboger@ uwaterloo.ca
John Munoz	Systems Design Engineering	Collaborator	john.munoz.hci@ uwaterloo.ca
Aishwarya Aravamuthan	Systems Design Engineering	Student Investigato r	akaravam@ uwaterloo.ca
Katrin Fischer	Electrical and Computer Engineering	Research Assistant	katrin.fischer@ uwaterloo.ca

Shruti Chandra	Electrical and Computer Engineering	Collaborator	shruti.chandr@uwaterloo.ca

By signing this consent form, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

I have read the information presented in the information letter about a study being conducted by the research team as part of Aishwarya Aravamuthan's Master thesis led by Dr. Kerstin Dautenhahn and Dr Jennifer Boger from Systems Design Engineering at the University of Waterloo. Me and my child had the opportunity to ask any questions related to this study and to receive satisfactory answers to our questions.

I am aware that my child may withdraw my consent for any of the above statements or withdraw my child's participation during the data collection phase of the study without penalty by advising the researcher.

All sessions will be videotaped. The purpose of videotaping is for post-study data analysis and the participant's identity will not be revealed when used in publications or presentations. (i.e. while your child's face is visible based on your consent and identifiable data such as names will be removed).

This study has been reviewed and received ethics clearance through the University of Waterloo Research Ethics Committee. If you have questions for the Committee contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca.

Participant Name: ____
(Please print)

Parent's or legal guardian's Name:

____

Signature of parent or legal guardian

____

Witness Name:

____

(Please print)

Witness Signature: ______________________________________

Date: ____

Data use in future research

Additionally, I consent for data collected in this study to be used in future research. My consent / non-consent to the future use of data does not impact my child's participation in this study.

_______ I consent for my child's data to be used in future studies.
_______ I **DO NOT** consent for my child's data to be used in future studies.

_______ I consent using the video and pictures collected in the study to be used in academic publications and presentations.

_______ I **DO NOT** consent using the video and pictures collected in the study to be used in academic publications and presentations.

Appendix E

Assent Letter for child participant

Assent Letter and Form

Project Title -
Pepper: A mediator for intergenerational relationships

My name is Aishwarya and I am part of a group at the University of Waterloo who works with robots. Your parents have said that I could talk to you.

I would like to tell you about a study that involves playing a game with your grandparent and a robot. We want to see if you would like to be part of this study.

Purpose of the Study: We would like to study how a robot can help people play games together.

Procedure: If you decide you would like to be a part of this study, you and your grandparent will come to the University of Waterloo on three different days.

Each time, we will prepare a game that you can play together with your grandpa/grandma. We will explain how the game works during the session, so you don't have to prepare anything.

While you play the game, a robot will be there, too, and try to give you some tips for the game. The robot will be across the table from you and it won't be touching you or do anything scary.

Session1: We will show you a game called Tangram and you can play it together with your grandparent. We will also show you the robot for the first time.

Session 2: You will play the game with your grandparent and the robot will try to give you tips.

Session3: You will play the game with your grandparent and the robot will be there, too. The robot will again try to help you during the game, but it might say and do things in a slightly different way than last time.

What we hope to find out is how the robot can help people in playing a game. We cannot think of how being in this study could harm you. We will make sure that there is always a safe distance between you and the robot.

If we ask you questions that you do not want to answer, then tell us you do not want to answer those questions. If we ask you to do things you do not want to do then you can tell us that you do not want to do them.

The things you say and any information we write about you will not have your name with it, so no one other than you, your parents, your grandparent and us will know that you did this study. We will be recording a video of the session, so we can go back later and review how well the game worked. Only our research team will have access to the video and in case we need to show the video to someone else, for example at a presentation, your name will be removed while your face will be visible based on your parent's consent.

You do not have to be in the study. No one will get angry or upset with you if you don't want to do this. Just tell us if you don't want to be in the study. And if you decide to be in the study, but later you change your mind, then you can tell us at that time that you do not want to be in the study anymore.

You can ask questions at any time. You can talk to me or you can talk to someone else at any time during the study. You can ask now or you can ask later. If you want to ask later, you parent can help you to contact me.

ASSENT TO PARTICIPATE

I was present when (print participant's name) __________________________ was read this form and said that he or she agreed, or assented, to take part in this study

Witness Signature: ____

Date:
____

Appendix F

Demographic form

Demographic Information Form

Instructions: Please provide a response for each of the following questions:

Grandparent's age ____________ **Grandchild's age** ____________

Grandparent's gender ________________ **Grandchild's gender** ________________

How often do you play games together?

____

Which games do you play?

Electronic games ○ Board games ○ Other ○ __________

Appendix G

Interview Questions

Interview Questions (Stage 1)

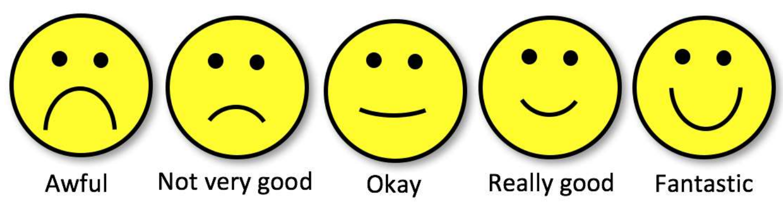
Level	Sub-stage	Topic	ID	Question
Introduction	Preliminary Questions Participants will be asked about games in general.	Games perception and previous experience	1	When was the last time you two played a game together? a) What game was it? b) How often do you play games together?
			2	Have you heard of a game called Tangram? Have you played it (how often)?
1.1 Human Mediator	Playing Tangram Participants will be invited to play the Tangram game	Tangram game experience	3	Which of these three shapes would you like to build?
			4	How was that? What did you think?
			5	If you were to describe what you think about the game using these faces [see scale in 19a)_CollaborationQuestionnaire_Stage1.pdf], which one would you pick?
1.2 Human Mediator and Pepper	Introduction of Pepper	Robot perception and past experience	6	Have you seen a robot before?
			7	What is your first impression? What do you think about Pepper?
			8	What do you think Pepper can do?
	Playing Tangram Participants will be invited to play the Tangram game while Pepper is present	Tangram Game experience with Pepper present	9	Which of these three shapes would you like to build?
			10	How was that? What did you think?
			11	If you were to describe what you think about the game using these faces [see scale in 19a)_CollaborationQuestionnaire_Stage1.pdf], which one would you pick?
		Assess reaction to Pepper	12	How did this round feel compared to the other one?
			13	How did Pepper make you feel? Why? What specifically made you think that?

			14	Let's imagine that Pepper learned how to play Tangram from observing you today. Would you like Pepper to be here the next time you play Tangram? Why/Why not?
			15	What would Pepper be doing?
Overall Experience	Follow Up	Game user experience	16	Tell me some things you liked today.
			17	What are some things you didn't care for?
			18	Is there anything else you would like to share?
	Questionnaire	Collaboration	19	How well did you communicate today?
			20	How well did the two of you work together while playing Tangram?
			21	How well did you solve problems together?
	Wrap-up	Conclusion of session	22	Before we finish, do you have any additional comments about today's session or questions for me?

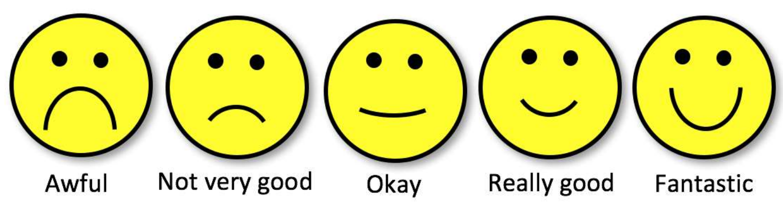
Appendix H

Questionnaire

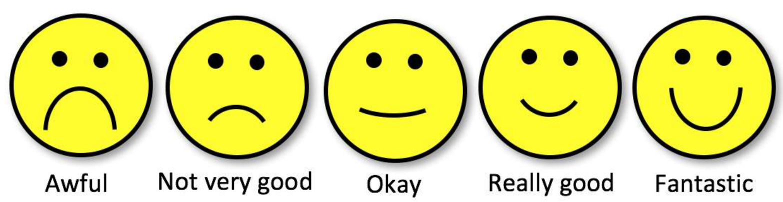
How well did you communicate today?



How well did the two of you work together while playing Tangram?



How well did you solve problems together?



Appendix I

Letter of Appreciation for Participants

University of Waterloo

Project: Pepper: A mediator for intergenerational relationships

Letter of Appreciation

Thank you for participating in the study - Pepper: A mediator for intergenerational relationships

Dear [Participant's name],

We would like to thank you for your participation in this study. As a reminder, the purpose of this study is to improve our design as we develop a robot-mediated Tangram game to foster intergenerational relationships. Our goal is to test whether our game can foster intergenerational relationships.

Please remember that any data pertaining to you as an individual will be kept confidential. If you are interested in receiving more information regarding the results of this project, or if you have any questions or concerns, please contact us through the study's Principal Investigator, Dr Kerstin Dautenhahn, at kerstin.dautenhahn@uwaterloo.ca.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#). If you have questions for the Committee contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca

Sincerely,

Social and Intelligent Robotics Research Team

Appendix J

Letter of Appreciation for Parents/Legal Guardian

Project: Pepper: A mediator for intergenerational relationships

Letter of Appreciation

Thank you for participating in the study - Pepper: A mediator for intergenerational relationships

Dear [Parent's name],

We would like to thank you for allowing your child to participate in this study. As a reminder, the purpose of this study is to improve our design as we develop a robot-mediated Tangram game to foster intergenerational relationships. Our goal is to test whether our game can foster intergenerational relationships.

Please remember that any data pertaining to your child as an individual will be kept confidential. If you are interested in receiving more information regarding the results of this project, or if you have any questions or concerns, please contact us through the study's Principal Investigator, Dr Kerstin Dautenhahn, at kerstin.dautenhahn@uwaterloo.ca.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#). If you have questions for the Committee contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca

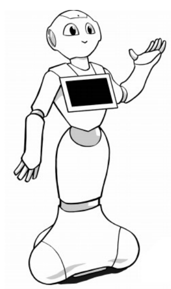
Sincerely,

Social and Intelligent Robotics Research Team

Appendix K

Certificate of Appreciation for child participants

Certificate of Appreciation



PRESENTED TO

FOR OUTSTANDING PARTICIPATION

IN A STUDY WITH PEPPER THE ROBOT

STUDY COORDINATOR

DATE

Appendix L

Recruitment Flyer

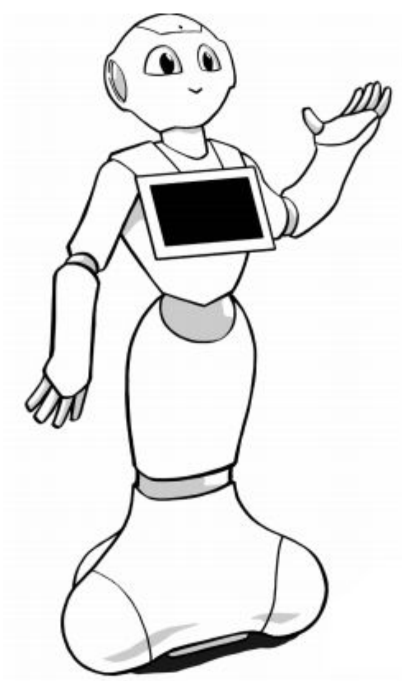
University of Waterloo

SIRRL | Social and Intelligent Robotics Research Laboratory

itwil | Intelligent Technologies for Wellness and Independent Living Lab

SEEKING PARTICIPANTS FOR MULTI-STAGE STUDY ON ROBOT-MEDIATED INTERGENERATIONAL GAME

We are looking for grandparents to participate in our study with their grandchild



Participant Criteria:

Grandparent:

- Age doesn't matter, must have a grandchild (6-10 years)
- Must be able to travel to the study location.
- Should be able to understand and speak English.
- Normal to corrected vision.

Grandchild:

- 6-10 years of age.
- Should be able to understand and speak English

As a participant in this study, you would be asked to:

- Come to the University of Waterloo for three sessions.
- Play a game with your grandchild and a robot assistant in three sessions.
- We will obtain parent's consent for your grandchild.

Each session will take approximately 60-90 minutes

You and your grandchild will receive a gift card of 30$ each at the end of the third session as well as a photograph of you and your grandchild playing with the robot for your participation.

For more information about this study, or to volunteer as a participant, please contact:

Aishwarya K Aravamuthan
MASc student,
Systems Design Engineering
Email: akaravam@uwaterloo.ca

This study has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee.

Appendix M

Recruitment Flyer for stage 3

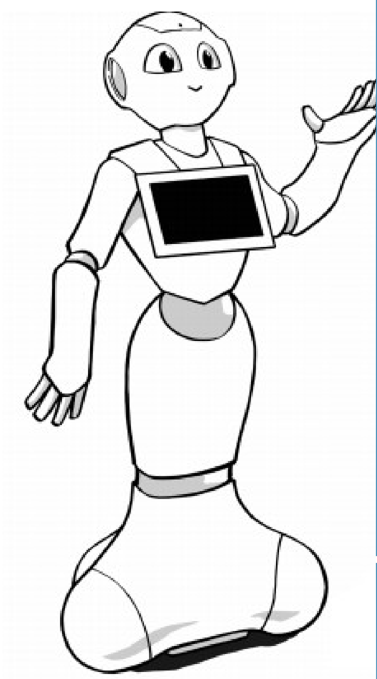
University of Waterloo

SIRRL | Social and Intelligent Robotics Research Laboratory

itwil | Intelligent Technologies for Wellness and Independent Living Lab

SEEKING PARTICIPANTS FOR A STUDY ON ROBOT-MEDIATED INTERGENERATIONAL GAME

We are looking for grandparents to participate in our study with their grandchild



Participant Criteria:

Grandparent:

- Age doesn't matter, must have a grandchild (6-10 years)
- Must be able to travel to the study location.
- Should be able to understand and speak English.
- Normal to corrected vision.

Grandchild:

- 6-10 years of age.
- Should be able to understand and speak English.

As a participant in this study, you would be asked to:

- Come to the University of Waterloo and play a game with your grandchild and a robot assistant.
- We will obtain parent's consent for your grandchild.

The session will take approximately 60-90 minutes

You and your grandchild will receive a gift card of 10$ each at the end of the session as well as a photograph of you and your grandchild playing with the robot for your participation.

For more information about this study, or to volunteer as a participant, please contact:

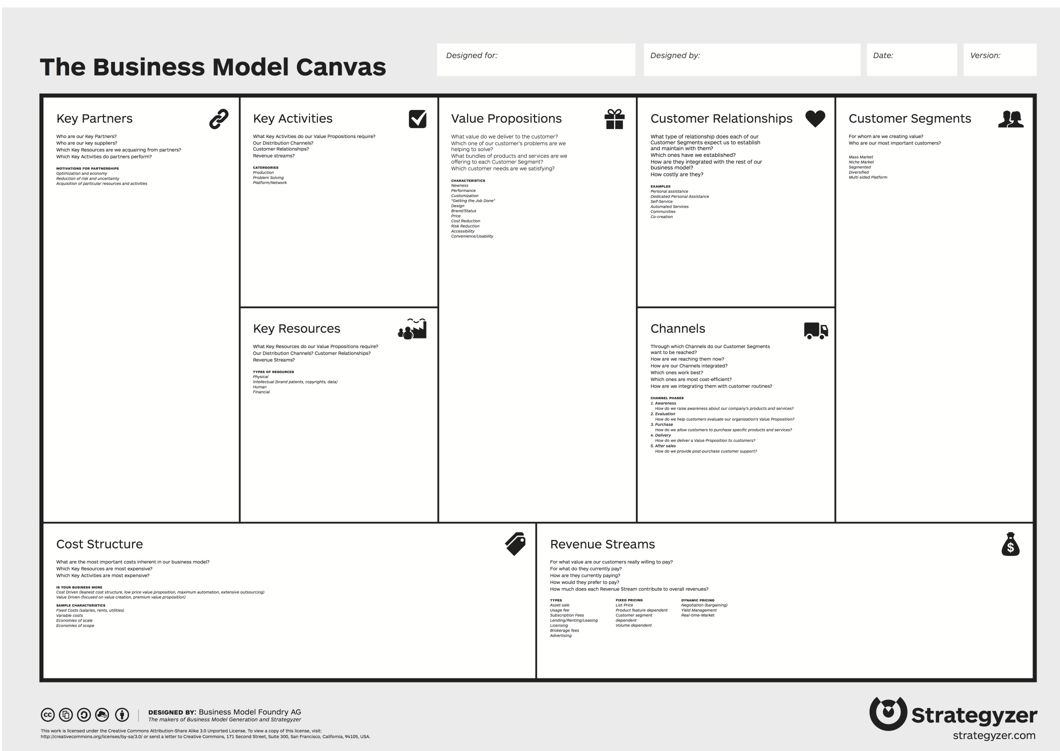
Aishwarya K Aravamuthan
MASc student,
Systems Design Engineering
Email: akaravam@uwaterloo.ca

This study has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee.

Ver.1 09 Dec 2019

Appendix N

Business Model Canvas



Appendix O

Test run 1 Canvases for researcher's work

STUDY TITLE

PURPOSE
(Purpose of the system, including its goal)

Create an accessible game for children with special needs to play with their peers and caretakers

RISKS
(e.g. Physical, Psychological, Data privacy/Security)

N/A

KEY ELEMENTS

Game

Genre: Role-play, action
(e.g. Puzzle, role play, strategy, simulation, action)

Format: Collaborative, competitve
(Collaborative, cooperative, competitive)

Medium: Physical
(Physical, digital, hybrid)

Players

Number of players: 2 human players, robotic agents
(Number of players in the game)

Age of players: Children

Relationship: Peers, strangers, family members
(e.g. Family members, strangers, peers)

Gender: N/A

Location: Remote and in-person (in-person preferred)
(e.g. In-person, remote)

Social Agent

Type: Animal-like, abstract
(e.g. Humanoid, Animal-like, Toy-like)

Presence: Physical
(Physical, virtual or both)

Interaction with players: Teleoperation/motion
(e.g. Motion, manipulation, touch, screen, speech)

INTERACTION METRIC OF PLAYERS

Verbal: Speech with other participants (possible with robot but early to tell)
(e.g. Speech)

Non-verbal: LED, motion
(e.g. Face: Expression, eye gaze, head pose; Body: Posture, Gesture; Proxemics; paralanguage: pitch, volume)

Game performance: Balls scored in goal
(e.g. score, task completion rate)

GAME DESIGN TETRAD MODEL

Mechanics:
(Game procedure, rules, and goals, e.g. social interaction, role play)

Collect balls
Aim at goal
Score goal
Communicate with other players

Story:
(Events that unfold in the game, e.g. interactive narrative, real-life problems)

Narrative

Aesthetics:
(How the game looks and feels, e.g. visuals, game contextualization, player-centric aesthetics)

Robot design
game contextualization

Technology:
(Elements, materials and interfaces needed for the game to be played, e.g. cards, controllers, customizable interfaces, digital components)

Robot
Vision
Robot autonomy

(Note some elements will come under more than one category)

GAMEPLAY CONSIDERATIONS

Role of players:
(e.g. Peer, Mentor, Mediator, Bystander)

Peer

Role of robot:
(e.g.Peer, Mentor, Mediator, Bystander)

Gameplay agent

Division of labor:
(how roles and responsibilities are shared among the players and robot)

Human teleoperated/helps robot

SOCIAL INTERACTION OF THE PLAYERS

Socialization style:
(e.g. Democratic, Authoritarian)

Authoritatrian

Social behavior:
(e.g. Guidance, Affiliation, Dominance)

Guidance, Affiliation, Dominance

ROBOTIC ELEMENTS
(Note: This section is focused on the components that are used in the session. Do not include post-session analysis here)

Software application: ROS
(software required to run the session e.g. robot control software)

Sensors: Camera
(built-in sensors of the robot and external sensors that collect data during the session e.g. cameras, microphone, tactile sensors)

Feature extraction tools: OpenCV
(tools required to extract the features during the session e.g. OpenCV, OpenPose)

Algorithms: Simple image analysis, simple state machine
(algorithms used in the session e.g. decision-making algorithms)

Actuators: Robot motion, ball collection, ball shooting
(actuators e.g. robot head position, robot arm control, motion control)

SYSTEM EVALUATION
(Note: Metrics used to determine the "success" of the system; what data are you going to collect and how are you going to analyze it?)

Player performance Gaze at robot, smiling, balls scored, wanting to play again
(e.g.metrics to measure the interaction level, collaboration, engagement)

Game performance Balls scored
(e.g. Quantitative performance- effectiveness, efficiency; subjective ratings, appropriate utilization of mixed-initiative)

Agent performance Autonomy
(e.g. self-awareness, human awareness, autonomy)

Operator performance (WoZ)
(e.g. Situation awareness, timeliness, workload, accuracy of mental models of device operation)

No WoZ as participant is the one controlling the robot

STUDY TITLE

PURPOSE
(Purpose of the system, including its goal)

To help individuals with social anxiety overcome their anxiety through practicing required skills and relaxation techniques with robot

RISKS
(e.g. Physical, Psychological, Data privacy/Security)

Physical: Robot falling – we need to maintain a safe distance between the robot and participants to prevent robot from falling

KEY ELEMENTS

Game

Genre: Role play, simulation
(e.g. Puzzle, role play, strategy, simulation, action)

Format: competitive
(Collaborative, cooperative, competitive)

Medium: hybrid
(Physical, digital, hybrid)

Players

Number of players: 1 or 2
(Number of players in the game)

Age of players: Young people

Relationship: Peers or stranger
(e.g. Family members, strangers, peers)

Gender: Same or different

Location: In-person
(e.g. In-person, remote)

Social Agent

Type: Humanoid
(e.g. Humanoid, Animal-like, Toy-like)

Presence: Physical or virtual
(Physical, virtual or both)

Interaction with players: Motion, screen, speech, touch
(e.g. Motion, manipulation, touch, screen, speech)

INTERACTION METRIC OF PLAYERS

Verbal: Talking time
(e.g. Speech)

Non-verbal: Eye gaze, head pose, body posture and gesture
(e.g. Face: Expression, eye gaze, head pose; Body: Posture, Gesture; Proxemics; paralanguage: pitch, volume)

Game performance: Score and task completion rate
(e.g. score, task completion rate)

GAME DESIGN TETRAD MODEL

Mechanics:
(Game procedure, rules, and goals, e.g. social interaction, role play)

Using a dice, the robot and the participant arrive at different locations on a game board. Each location specifies a particular social skill that needs practice and participants perform the social skill they arrive at on the game board. Scores are allotted for performing the skill. The scores vary based on the inherent difficulty of the task. Higher scores will be allotted for performing more complex social skills. The party with the most points wins the game.

Story:
(Events that unfold in the game, e.g. interactive narrative, real-life problems)

Real-life problems

Aesthetics:
(How the game looks and feels, e.g. visuals, game contextualization, player-centric aesthetics)

visuals

Technology:
(Elements, materials and interfaces needed for the game to be played, e.g. cards, controllers, customizable interfaces, digital components)

1-Game board
2- Robot

(Note some elements will come under more than one category)

GAMEPLAY CONSIDERATIONS

Role of players:
(e.g. Peer, Mentor, Mediator, Bystander)

peer

Role of robot:
(e.g.Peer, Mentor, Mediator, Bystander)

Peer for one participant or mediator for more than one participant

Division of labor:
(how roles and responsibilities are shared among the players and robot)

Using a dice, participants perform the social skill they arrive at on the game board.

SOCIAL INTERACTION OF THE PLAYERS

Socialization style:
(e.g. Democratic, Authoritarian)

Democratic.

Social behavior:
(e.g. Guidance, Affiliation, Dominance)

-

ROBOTIC ELEMENTS
(Note: This section is focused on the components that are used in the session. Do not include post-session analysis here)

Software application: choregraphe
(software required to run the session e.g. robot control software)

Sensors: Cameras, microphone
(built-in sensors of the robot and external sensors that collect data during the session e.g. cameras, microphone, tactile sensors)

Feature extraction tools: Speech Recognition, Open Face, Open Pose
(tools required to extract the features during the session e.g. OpenCV, OpenPose)

Algorithms:
(algorithms used in the session e.g. decision-making algorithms)

Actuators: verbal comments, tablet
(actuators e.g. robot head position, robot arm control, motion control)

SYSTEM EVALUATION
(Note: Metrics used to determine the "success" of the system; what data are you going to collect and how are you going to analyze it?)

Player performance collaboration
(e.g.metrics to measure the interaction level, collaboration, engagement)

Game performance Quantitative performance,
(e.g. Quantitative performance- effectiveness, efficiency; subjective ratings, appropriate utilization of mixed-initiative)

Agent performance autonomy
(e.g. self-awareness, human awareness, autonomy)

Operator performance (WoZ)
(e.g. Situation awareness, timeliness, workload, accuracy of mental models of device operation)

Appendix P

Test run 1 Canvases for the case-study application

STUDY TITLE

PURPOSE
(Purpose of the system, including its goal)

Figure out how to develop robotic systems for remote human-human interaction

RISKS
(e.g. Physical, Psychological, Data privacy/Security)

Data privacy (video conferencing)

KEY ELEMENTS

Game

Genre: Maze
(e.g. Puzzle, role play, strategy, simulation, action)

Format: Collaborative
(Collaborative, cooperative, competitive)

Medium: Physical, digital
(Physical, digital, hybrid)

Players

Number of players: 2 human players, robotic agents
(Number of players in the game)

Age of players: Adults (18-53)

Relationship: strangers
(e.g. Family members, strangers, peers)

Gender: Male

Location: Remote (in-lab)
(e.g. In-person, remote)

Social Agent

Type: Animal-like
(e.g. Humanoid, Animal-like, Toy-like)

Presence: Physical, virtual
(Physical, virtual or both)

Interaction with players: Touch, screen, video conferencing
(e.g. Motion, manipulation, touch, screen, speech)

INTERACTION METRIC OF PLAYERS

Verbal: Speech with other remote participant
(e.g. Speech)

Non-verbal: Eye gaze, petting
(e.g. Face: Expression, eye gaze, head pose; Body: Posture, Gesture; Proxemics; paralanguage: pitch, volume)

Game performance: Bones found/points
(e.g. score, task completion rate)

GAME DESIGN TETRAD MODEL

Mechanics:
(Game procedure, rules, and goals, e.g. social interaction, role play)

Find hidden bones
Keep track of AIBO's internal states (role playing component)
Collaborate with remote human player

Story:
(Events that unfold in the game, e.g. interactive narrative, real-life problems)

N/A

Aesthetics:
(How the game looks and feels, e.g. visuals, game contextualization, player-centric aesthetics)

Visuals
game contextualization

Technology:
(Elements, materials and interfaces needed for the game to be played, e.g. cards, controllers, customizable interfaces, digital components)

Robot
video conferencing
Vision
Robot coordination and autonomy

(Note some elements will come under more than one category)

GAMEPLAY CONSIDERATIONS

Role of players:
(e.g. Peer, Mentor, Mediator, Bystander)

Peer

Role of robot:
(e.g.Peer, Mentor, Mediator, Bystander)

Mediator

Division of labor:
(how roles and responsibilities are shared among the players and robot)

Human is guide/motivator

SOCIAL INTERACTION OF THE PLAYERS

Socialization style:
(e.g. Democratic, Authoritarian)

Democratic

Social behavior:
(e.g. Guidance, Affiliation, Dominance)

Guidance

ROBOTIC ELEMENTS
(Note: This section is focused on the components that are used in the session. Do not include post-session analysis here)

Software application: AiBone
(software required to run the session e.g. robot control software)

Sensors: Camera, tactile (for petting)
(built-in sensors of the robot and external sensors that collect data during the session e.g. cameras, microphone, tactile sensors)

Feature extraction tools: Not-mentioned
(tools required to extract the features during the session e.g. OpenCV, OpenPose)

Algorithms: Internal state management
(algorithms used in the session e.g. decision-making algorithms)

Actuators: Robot motion
(actuators e.g. robot head position, robot arm control, motion control)

SYSTEM EVALUATION
(Note: Metrics used to determine the "success" of the system; what data are you going to collect and how are you going to analyze it?)

Player performance Gaze at robot, speech with other human
(e.g.metrics to measure the interaction level, collaboration, engagement)

Game performance Points scored, bones found
(e.g. Quantitative performance- effectiveness, efficiency; subjective ratings, appropriate utilization of mixed-initiative)

Agent performance Unclear abut this. Autonomy
(e.g. self-awareness, human awareness, autonomy)

Operator performance (WoZ)
(e.g. Situation awareness, timeliness, workload, accuracy of mental models of device operation)

NA

STUDY TITLE

PURPOSE
(Purpose of the system, including its goal)

Supporting human-human communication in remote interaction scenarios (help to maintain and strengthen participants' distanced relationship)

RISKS
(e.g. Physical, Psychological, Data privacy/Security)

KEY ELEMENTS

Game

Genre: Maze
(e.g. Puzzle, role play, strategy, simulation, action)

Format: Collaborative
(Collaborative, cooperative, competitive)

Medium: Hybrid
(Physical, digital, hybrid)

Players

Number of players: 2
(Number of players in the game)

Age of players: Young people

Relationship: Peers (University students)
(e.g. Family members, strangers, peers)

Gender: only male participants

Location: remote
(e.g. In-person, remote)

Social Agent

Type: Animal-like
(e.g. Humanoid, Animal-like, Toy-like)

Presence: Physical
(Physical, virtual or both)

Interaction with players: sniffing behaviour and sound, head movement
(e.g. Motion, manipulation, touch, screen, speech)

INTERACTION METRIC OF PLAYERS

Verbal: Frequency and content of the Speech to other participant
(e.g. Speech)

Non-verbal: Eye gaze, Smiles
(e.g. Face: Expression, eye gaze, head pose; Body: Posture, Gesture; Proxemics; paralanguage: pitch, volume)

Game performance: score
(e.g. score, task completion rate)

GAME DESIGN TETRAD MODEL

Mechanics:
(Game procedure, rules, and goals, e.g. social interaction, role play)

If participants want to be efficient at each level, cooperation is highly encouraged to cover every spot of the maze and thus maximize the score in the limited time.
keep the Energy and Mood values in sufficient levels.

Story:
(Events that unfold in the game, e.g. interactive narrative, real-life problems)

Finding the hidden bones in the given time

Aesthetics:
(How the game looks and feels, e.g. visuals, game contextualization, player-centric aesthetics)

visuals

Technology:
(Elements, materials and interfaces needed for the game to be played, e.g. cards, controllers, customizable interfaces, digital components)

Computer, AIBO robot

Webcam, microphone, Internet conference software (i.e. Skype),

(Note some elements will come under more than one category)

GAMEPLAY CONSIDERATIONS

Role of players:
(e.g. Peer, Mentor, Mediator, Bystander)

peer

Role of robot:
(e.g.Peer, Mentor, Mediator, Bystander)

Mediator

Division of labor:
(how roles and responsibilities are shared among the players and robot)

Each participant was seated in front of a computer with an AIBO robot, and then started communicating with the other participant located in a separate room to play a collaborative computer game.

SOCIAL INTERACTION OF THE PLAYERS

Socialization style:
(e.g. Democratic, Authoritarian)

Democratic

Social behavior:
(e.g. Guidance, Affiliation, Dominance)

Guidance, Affiliation

ROBOTIC ELEMENTS
(Note: This section is focused on the components that are used in the session. Do not include post-session analysis here)

Software application: AiBone system
(software required to run the session e.g. robot control software)

Sensors: Camera,
(built-in sensors of the robot and external sensors that collect data during the session e.g. cameras, microphone, tactile sensors)

Feature extraction tools: AiBone system
(tools required to extract the features during the session e.g. OpenCV, OpenPose)

Algorithms: -
(algorithms used in the session e.g. decision-making algorithms)

Actuators: Robot head position
(actuators e.g. robot head position, robot arm control, motion control)

SYSTEM EVALUATION
(Note: Metrics used to determine the "success" of the system; what data are you going to collect and how are you going to analyze it?)

Player performance degree of cooperation
(e.g.metrics to measure the interaction level, collaboration, engagement)

Game performance Quantitative performance
(e.g. Quantitative performance- effectiveness, efficiency; subjective ratings, appropriate utilization of mixed-initiative)

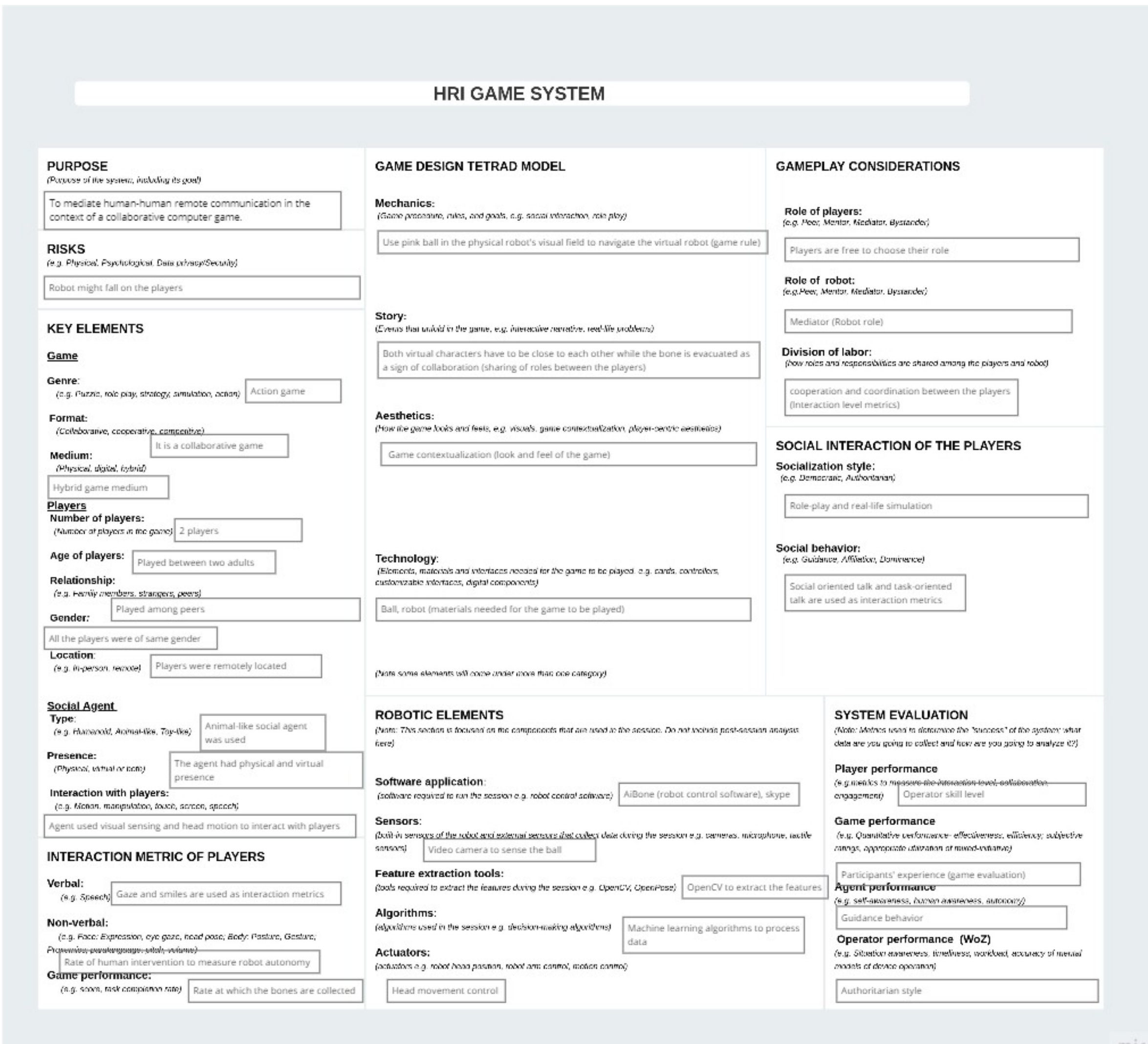
Agent performance autonomy
(e.g. self-awareness, human awareness, autonomy)

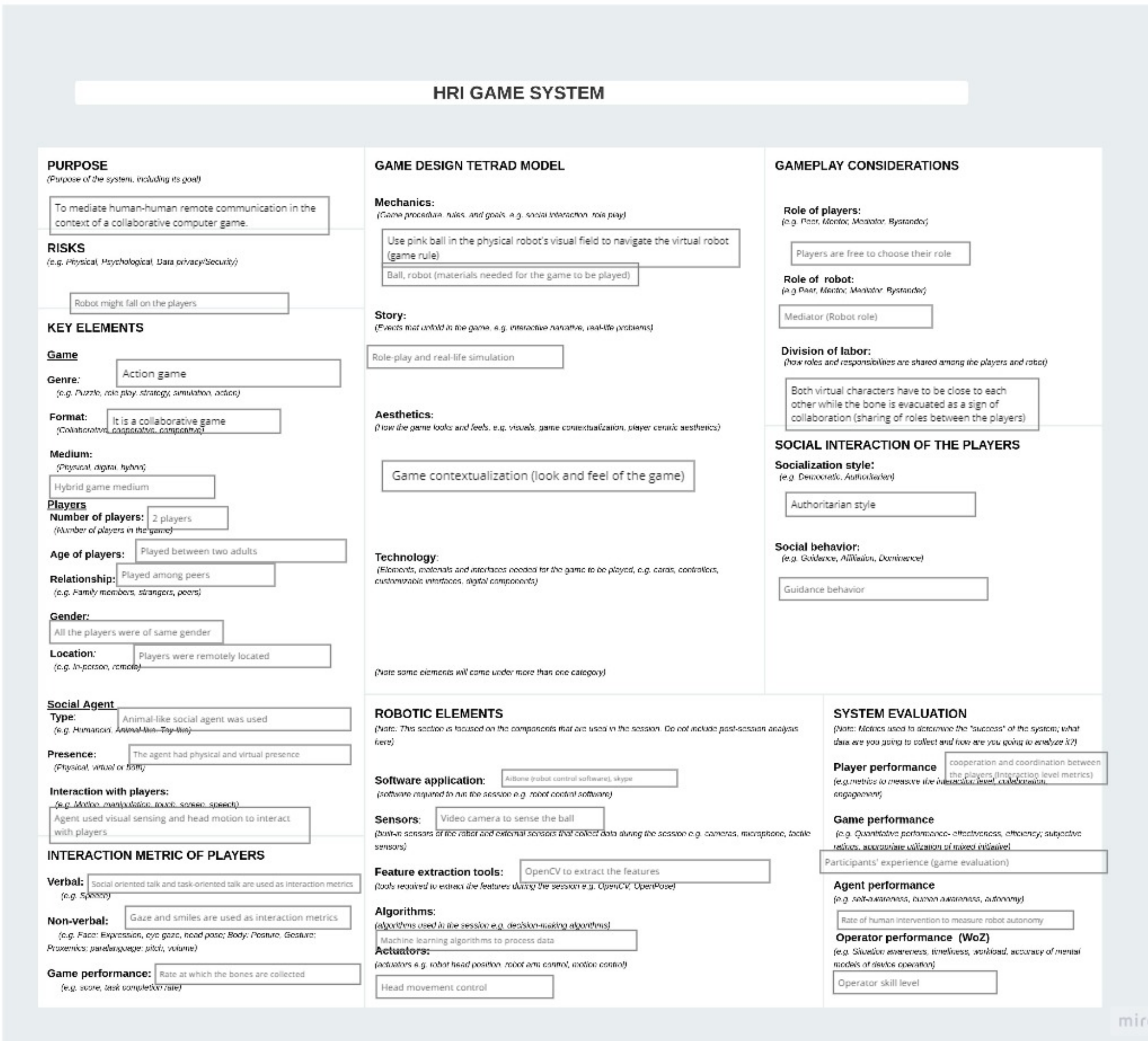
Operator performance (WoZ)
(e.g. Situation awareness, timeliness, workload, accuracy of mental models of device operation)

-

Appendix Q

Test run 2 Canvases


HRI GAME SYSTEM
PURPOSE
(Purpose of the system, including its goal)
To mediate human-human remote communication in the context of a collaborative computer game.
RISKS
(e.g. Physical, Psychological, Data privacy/Security)
Robot might fall on the players
KEY ELEMENTS
Game
Genre:
(e.g. Puzzle, role play, strategy, simulation, action)
Action game
Format:
(Collaborative, cooperative, competitive)
It is a collaborative game
Medium:
(Physical, digital, hybrid)
Hybrid game medium
Players
Number of players:
(Number of players in the game)
2 players
Age of players:
Played between two adults
Relationship:
(e.g. Family members, strangers, peers)
Played among peers
Gender:
All the players were of same gender
Location:
(e.g. In-person, remote)
Players were remotely located
Social Agent
Type:
(e.g. Humanoid, Animal-like, Toy-like)
Animal-like social agent was used
Presence:
(Physical, virtual or both)
The agent had physical and virtual presence
Interaction with players:
(e.g. Motion, manipulation, touch, screen, speech)
Agent used visual sensing and head motion to interact with players
INTERACTION METRIC OF PLAYERS
Verbal:
(e.g. Speech)
Gaze and smiles are used as interaction metrics
Non-verbal:
(e.g. Face: Expression, eye gaze, head pose; Body: Posture, Gesture, Proxemics; paralanguage: pitch, volume)
Rate of human intervention to measure robot autonomy
Game performance:
(e.g. score, task completion rate)
Rate at which the bones are collected
GAME DESIGN TETRAD MODEL
Mechanics:
(Game procedure, rules, and goals, e.g. social interaction, role play)
Use pink ball in the physical robot's visual field to navigate the virtual robot (game rule)
Story:
(Events that unfold in the game, e.g. interactive narrative, real-life problems)
Both virtual characters have to be close to each other while the bone is evacuated as a sign of collaboration (sharing of roles between the players)
Aesthetics:
(How the game looks and feels, e.g. visuals, game contextualization, player-centric aesthetics)
Game contextualization (look and feel of the game)
Technology:
(Elements, materials and interfaces needed for the game to be played, e.g. cards, controllers, customizable interfaces, digital components)
Ball, robot (materials needed for the game to be played)
(Note some elements will come under more than one category)
GAMEPLAY CONSIDERATIONS
Role of players:
(e.g. Peer, Mentor, Mediator, Bystander)
Players are free to choose their role
Role of robot:
(e.g.Peer, Mentor, Mediator, Bystander)
Mediator (Robot role)
Division of labor:
(how roles and responsibilities are shared among the players and robot)
cooperation and coordination between the players (Interaction level metrics)
SOCIAL INTERACTION OF THE PLAYERS
Socialization style:
(e.g. Democratic, Authoritarian)
Role-play and real-life simulation
Social behavior:
(e.g. Guidance, Affiliation, Dominance)
Social oriented talk and task-oriented talk are used as interaction metrics
ROBOTIC ELEMENTS
(Note: This section is focused on the components that are used in the session. Do not include post-session analysis here)
Software application:
(software required to run the session e.g. robot control software)
AiBone (robot control software), skype
Sensors:
(built-in sensors of the robot and external sensors that collect data during the session e.g. cameras, microphone, tactile sensors)
Video camera to sense the ball
Feature extraction tools:
(tools required to extract the features during the session e.g. OpenCV, OpenPose)
OpenCV to extract the features
Algorithms:
(algorithms used in the session e.g. decision-making algorithms)
Machine learning algorithms to process data
Actuators:
(actuators e.g. robot head position, robot arm control, motion control)
Head movement control
SYSTEM EVALUATION
(Note: Metrics used to determine the "success" of the system: what data are you going to collect and how are you going to analyze it?)
Player performance
(e.g. metrics to measure the interaction level, collaboration, engagement)
Operator skill level
Game performance
(e.g. Quantitative performance- effectiveness, efficiency; subjective ratings, appropriate utilization of mixed-initiative)
Participants' experience (game evaluation)
Agent performance
(e.g. self-awareness, human awareness, autonomy)
Guidance behavior
Operator performance (WoZ)
(e.g. Situation awareness, timeliness, workload, accuracy of mental models of device operation)
Authoritarian style
miro



HRI GAME SYSTEM

PURPOSE
(Purpose of the system, including its goal)

To mediate human-human remote communication in the context of a collaborative computer game.

RISKS
(e.g. Physical, Psychological, Data privacy/Security)

Robot might fall on the players

KEY ELEMENTS

Game

Genre: Action game
(e.g. Puzzle, role play, strategy, simulation, action)

Format: It is a collaborative game
(Collaborative, cooperative, competitive)

Medium:
(Physical, digital, hybrid)
Hybrid game medium

Players

Number of players: 2 players
(Number of players in the game)

Age of players: Played between two adults

Relationship: Played among peers
(e.g. Family members, strangers, peers)

Gender:
All the players were of same gender

Location: Players were remotely located
(e.g. In-person, remote)

Social Agent

Type: Animal-like social agent was used
(e.g. Humanoid, Animal-like, Toy-like)

Presence: The agent had physical and virtual presence
(Physical, virtual or both)

Interaction with players:
(e.g. Motion, manipulation, touch, sensor, speech)
Agent used visual sensing and head motion to interact with players

INTERACTION METRIC OF PLAYERS

Verbal: Social oriented talk and task-oriented talk are used as interaction metrics
(e.g. Speech)

Non-verbal: Gaze and smiles are used as interaction metrics
(e.g. Face: Expression, eye gaze, head pose; Body: Posture, Gesture; Proxemics; paralanguage: pitch, volume)

Game performance: Rate at which the bones are collected
(e.g. score, task completion rate)

GAME DESIGN TETRAD MODEL

Mechanics:
(Game procedure, rules, and goals, e.g. social interaction, role play)
Use pink ball in the physical robot's visual field to navigate the virtual robot (game rule)
Ball, robot (materials needed for the game to be played)

Story:
(Events that unfold in the game, e.g. interactive narrative, real-life problems)
Role-play and real-life simulation

Aesthetics:
(How the game looks and feels, e.g. visuals, game contextualization, player centric aesthetics)
Game contextualization (look and feel of the game)

Technology:
(Elements, materials and interfaces needed for the game to be played, e.g. cards, controllers, customizable interfaces, digital components)

(Note some elements will come under more than one category)

GAMEPLAY CONSIDERATIONS

Role of players:
(e.g. Peer, Mentor, Mediator, Bystander)
Players are free to choose their role

Role of robot:
(e.g. Peer, Mentor, Mediator, Bystander)
Mediator (Robot role)

Division of labor:
(how roles and responsibilities are shared among the players and robot)
Both virtual characters have to be close to each other while the bone is evacuated as a sign of collaboration (sharing of roles between the players)

SOCIAL INTERACTION OF THE PLAYERS

Socialization style:
(e.g. Democratic, Authoritarian)
Authoritarian style

Social behavior:
(e.g. Guidance, Affiliation, Dominance)
Guidance behavior

ROBOTIC ELEMENTS
(Note: This section is focused on the components that are used in the session. Do not include post-session analysis here)

Software application: AiBone (robot control software), skype
(software required to run the session e.g. robot control software)

Sensors: Video camera to sense the ball
(built-in sensors of the robot and external sensors that collect data during the session e.g. cameras, microphone, tactile sensors)

Feature extraction tools: OpenCV to extract the features
(tools required to extract the features during the session e.g. OpenCV, OpenPose)

Algorithms:
(algorithms used in the session e.g. decision-making algorithms)
Machine learning algorithms to process data

Actuators:
(actuators e.g. robot head position, robot arm control, motion control)
Head movement control

SYSTEM EVALUATION
(Note: Metrics used to determine the "success" of the system; what data are you going to collect and how are you going to analyze it?)

Player performance cooperation and coordination between the players (Interaction level metrics)
(e.g. metrics to measure the interaction level, collaboration, engagement)

Game performance
(e.g. Quantitative performance- effectiveness, efficiency; subjective ratings, appropriate utilization of mixed initiative)
Participants' experience (game evaluation)

Agent performance
(e.g. self-awareness, human awareness, autonomy)
Rate of human intervention to measure robot autonomy

Operator performance (WoZ)
(e.g. Situation awareness, timeliness, workload, accuracy of mental models of device operation)
Operator skill level