LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN
Department "Institut für Informatik"
Lehr- und Forschungseinheit Medieninformatik
Prof. Dr. Heinrich Hußmann

Bachelor's Thesis

Tangible User Interface for Supporting Goal Interdependence

Zhenhan Gao
Zhenhan.Gao@campus.lmu.de

Editing Period:	20.09.2021 - 07.02.2022
Supervisor:	Amy Yanhong Li
Responsible University Lecturer:	Prof. Dr. Sven Mayer

Zusammenfassung

Positive Interdependence ist eines der fünf wesentlichen Elemente für erfolgreiche kooperative Aktivitäten. Es bedeutet, dass sich alle Mitglieder aufeinander verlassen sollten, um erfolgreich zu sein, und dass sie glauben, dass sie nur dann "gewinnen" können, wenn sie zusammenhalten. Tangible User Interfaces (TUI) können Kindern helfen, Aufgaben effektiver zu lösen, neue Denkweisen zu erforschen und größere Lernfortschritte in der Gruppe zu erzielen. Obwohl frühere Studien TUI und Graphical User Interfaces (GUI) für die Gruppenarbeit verglichen haben, gab es nur wenige Studien, die sich auf die Gestaltung Positive Goal Interdependence konzentrierten. Daher wurde in meiner Bachelorarbeit ein Labyrinthspiel namens *CollabMaze* für Kinder im Schulalter entwickelt. Es wurde von einer Konzeptidee (Positive Goal Interdependence) zu einem benutzbaren Prototyp in dem GUI und TUI zur Unterstützung Positive Goal Interdependence entwickelt. Ich führte eine Nutzerstudie mit 20 Kindern im Alter von 6 bis 10 Jahren durch. Die wichtigsten Ergebnisse waren: (1) Sowohl TUI- als auch GUI-Kinder haben viel Spaß und eine hohe Zielabhängigkeit; (2) TUI hat eine bessere Erschwinglichkeit; (3) TUI kann Kindern mehr verbale Interaktion ermöglichen (insbesondere den Austausch von Ideen) als GUI; (4) TUI ist freundlicher für Kinder ohne Erfahrung im Umgang mit Technologie.

Abstract

Positive Interdependence is one of the five essential elements for successful collaborative activities. It refers that all members should rely on each other to succeed and believe that they can "win" only if they stick together. Tangible user interfaces (TUI) have the possibility to help children solve tasks more effectively, explore newer thinking and achieve greater learning gains in the group setting. Although previous studies have compared TUI and graphical user interfaces (GUI) for group work, few studies have been focused on positive goal interdependence design. Therefore, in my thesis study, a maze game called *CollabMaze* for school-aged children was designed. It started from a concept idea (positive goal interdependence) to a usable prototype in the GUI and TUI condition to support positive goal interdependence. I conducted a between-group user study with 20 children from 6 to 10 years old. The main findings were: (1) Both TUI and GUI children have high enjoyment and interdependence; (2) TUI has a better affordance; (3) TUI can facilitate more verbal interaction (especially sharing ideas) than GUI for children; (4) TUI is more friendly for children without technology use experience.

Task

Tangible learning is a novel way of learning in which students engage with their whole bodies. It has many advantages, including the ability to engage multiple senses to facilitate a constructive learning process, while also assisting spatial learning, facilitating social interaction and interacting with the same equipment at the same time.

A collaborative tangible learning environment can help children adapt to new conditions, and also provide an enjoyable learning environment by immersing them in a natural way. The aim of my thesis is to find out the differences between GUI and TUI for supporting positive goal interdependence, in terms of performance, engagement, enjoyment, usability and collaboration.

The work consists in:

- A literature review
- Designing and developing prototypes for GUI and TUI conditions to support positive goal interdependence
- Conducting a comparative user study to get feedback
- Evaluating the results of the user study

Ich erkläre hiermit, dass ich die vorliegende Arbeit selbstständig angefertigt, alle Zitate als solche kenntlich gemacht sowie alle benutzten Quellen und Hilfsmittel angegeben habe.

München, 7. Februar 2022 . . . . . . Zhenhan Gao . . . . . .

Contents

1 Introduction

Collaborative working transforms the traditional teacher-centered teaching model into a student-centered model [31]. In addition to facilitating idea exchanges, student-centered instruction encourages the building of students' self-esteem and confidence and helps to reduce anxiety and keep participants active in the learning process [18].

Nevertheless, not all collaborations bring these benefits [16]. In some cases, members' goals are not aligned, or some group members may feel that their efforts are irrelevant to the group's success and therefore are not motivated to contribute to the group [19, 16]. To avoid this situation, we need to know five basic elements of creating productive collaboration: positive interdependence, promotive interaction, individual accountability, small-group skills, and group processing [13]. Positive interdependence is an essential element that exists when group members perceive that they are interconnected and that one person's success is inseparable from the achievements of others in the group [32, 17, 14]. It helps to encourage students to work together rather than competing or individually, promoting more negotiation and communication to better resolve conflicts together rather than unilaterally [35]. If there is no positive interdependence, there is no collaboration. As a result, there are two conditions for creating positive goal interdependence, first, the instructor must build a clear group goal, such as ensuring that members learn the assigned material. Second, building constrained or codependent access points among members. These conditions are designed to ensure that each member is motivated to commit to working together and that everyone is held responsible for the success of the group.

Tangible User Interface (TUI) is a novel interface using the control of the physical object to build a bridge between the physical world and the digital world. It helps children who don't have computer skills because it is intuitive to know how to interact with [22]. In addition, with multiple input modalities and the ability to embody abstract concepts, TUI is a superior tool to facilitate collaborative learning. TUI provides particular affordances for fostering positive interdependence because the distributed work with particular duties brings object ownership and also because people have more desire to manipulate physical objects [33]. In contrast to TUI and the traditional physical user interface, Graphical User Interface (GUI) is a dominant interface in our daily lives such as smartphones and tablets. Children are now also being exposed to GUIs earlier and earlier, and even need to use tablets in class. TUI can compensate for the weaknesses of the GUI by adding the haptic signal to existing visual and auditory signals in order to create a greater presence in virtual environments and give participants a better performance [9]. However, in various studies comparing TUIs and GUIs, different and even contradictory findings are often found [40].

The goal of this thesis is to find out the differences between a traditional and tangible interface in supporting positive goal interdependence, in particular enjoyment and engagement. I designed a maze game called *CollabMaze* in both conditions that required two children to work together and find an exit. For TUI, two joysticks were designed to represent up/down and left/right, which can control the movement of the character in the maze to find an exit. As a comparison, a traditional condition (i.e., GUI) uses virtual buttons. I conducted a comparative user study to see the differences between TUI and GUI.

Regarding the thesis structure, first, a literature review in section 2 will explain the related work of TUI and positive interdependence, which serve as a foundation for developing the concept idea. Three research questions of my thesis are proposed in section 3. The creation and development of the TUI and GUI will be presented in section 4, which includes the design process, paper prototype, and concept idea. In section 5, I explain details of user study, containing participants, experimental process, and data analysis. section 6 will report the results of my user study and consequently discussed in section 7. section 8 is a summary of my whole study. Finally, limitations and future work will be discussed in section 9.

2 Related Work

2.1 Collaborative Learning for Children

Collaborative learning is an approach to teaching and learning in which learners with different levels of performance work together in small teams to achieve the same goal [12, 19]. In a collaborative learning environment, group members can interact with their partners, present and defend ideas and share different perspectives. Therefore, the most important part is the discussion and active work of the members, rather than the teacher's presentation and explanation as in the traditional teacher-centered instruction [31, 19]. The contribution of all members is required and the success of one member influences the other's success [8, 18].

Collaborative learning is very important in primary and secondary education [8]. In addition to increasing students' self-esteem and providing higher productivity, collaborative learning provides an environment to manage conflict resolution and, in particular, to reduce the incidence of violence [18]. Nevertheless, not all collaborations bring these benefits and in some non-collaborative groups such as the free-rider or hitchhiking effect can have a negative effect [16]. On one hand, sometimes dominated students do all the work, which makes the others could not contribute to group work (i.e., Unequal power) [34]. On the other hand, some group members may feel that their efforts are dispensable to the success of the group and therefore have less incentive to add to the group's performance, resulting in a reduced contribution [16].

A previous study with children has shown that there are some unexpected situations of conflict and competition in co-located collaborative work. Marshall et al. [21] designed a task for children in which they had to plan the seat in groups of three. The results showed that both in the digital interface (DiamondTouch tabletop) and physical interface (cardboard tokens) children used different strategies to refuse to share resources and work with other children. For example, the most common way was to move the shared materials out of reach or to physically fight for control, such as moving other children away. In particular, children used more possessive and aggressive strategies in the digital interface because it is more difficult to protect their ownership than in the physical interface.

To avoid this situation, there are five basic elements to ensure more productive outcomes: positive interdependence, promotive interaction, individual accountability, small-group skills, and group processing [13, 37, 18]. Although these elements are presented separately, they are interrelated with each other [16]. An environment without these five elements is not conducive to promoting collaborative learning.

2.2 Positive Goal Interdependence

From social interdependence theory, we have positive interdependence and negative interdependence [14]. Positive interdependence is a essential element of successful collaborative learning [13, 37, 18]. It means in a collaborative setting an individual's success is dependent on the group's success [17]. To make collaboration successful for everyone, all members should rely on one another and believe that working together is worthwhile [14, 17]. When individuals collaborate, they produce superior learning and working products than when they work alone because of the promotive interactions [14].

Positive goal interdependence is a type of positive interdependence and is the belief that each member can reach their goals only when the goals of the group are met. It is achieved by group members under two conditions: first, they must agree on a solution to the problem. For example, the instructor must build a clear group goal, such as ensuring that students acquire the required content [6]. Secondly, they must carry out the obligations of their distributed and assigned roles to create codependent access points, which require more than one action to achieve a good system response [32]. Other types of building positive interdependence include having shared rewards, relying on each other's resources, or dividing up work. Positive interdependence arises in true collaborative tasks. The purpose of creating positive interdependence is to encourage students to collaborate (not work individually or competitively), promote more negotiation, and improve conflict resolution (rather than unilateral action resulting from unresolved conflicts between members and thus failing to achieve success for both) [35].

2.3 Tangible Collaborative Learning

Tangible User Interface (TUI) is an interface that builds on the most basic skills people have in the physical world, namely interacting with real objects in a variety of ways, including touch, press, and grasp, as a basis for establishing a new possibility of connecting with digital worlds [29]. The main goal of TUI is therefore to give digital information physical forms and by providing physical representations and incarnations of digital information. TUI makes information immediately graspable and manipulable through haptic feedback [11].

Furthermore, some researchers found TUIs have the potential to promote understanding of abstract concepts and support learning. Especially for children in the early stages of cognitive development, the main way they explore new knowledge is through the intuitive and simple way of touching and manipulating objects [39]. Concrete objects are crucial for children's learning because when children are given concrete materials to manipulate, they might solve problems without symbolically imagining the rationale [23]. In fact, TUI can help children not only with their individual learning but also especially well-suited to collaborative learning [28, 20].

When it comes to collaborative activities, TUI is good at helping children solve tasks more effectively, exploring more new thinking, and achieving greater learning gains [28]. In addition, TUIs provide particular affordances for fostering positive interdependence because the distributed work with particular duties brings object ownership, and also people have more desire to manipulate physical objects [33]. The special advantage of TUI, "affordance" was proposed by Gibson to describe the certain physical characteristics of objects "naturally" reveal what they might be used for [23]. In order to better design TUI for supporting collaboration, Antle and Wise [2] designed 12 guidelines for TUI learning design, particularly for the collaboration part they mentioned the importance of creating codependent access points, which can force learners to negotiate with others. Later, they conducted an experiment of Youtopia [35], a tangible and interactive tabletop application that allows students to collaboratively plan for sustainable land. This study compared the pairs of children who were assigned particular roles in positive interdependence conditions and the other pairs who were not assigned roles in the control condition. The results showed that groups assigned specific roles spend more time explaining their thinking or reasoning to the partner than groups not assigned roles, but fewer conflicts. It means the assigned roles provide a positive effect on collaborative working. Nevertheless, in this study both the experimental and control groups were under the same interface type (TUI), and the differences of different interface types for supporting positive interdependence were not investigated. In another comparative study, also using Youtopia, Fan et al. [7] compared the differences between codependent and independent access points among university students. They found that the codependent design encouraged more equitable verbal and physical engagement than the independent design. Furthermore, codependent design supported more flexible collaboration and encouraged participants to discuss their ideas and aims. In contrast, the independent design led to parallel interaction, which implied non-collaboration.

Compared to other interfaces, TUI compensates for the use of human spatial abilities. It helps exploit our natural ability to interact with physical objects [30]. Graphical user interfaces (GUI) such as tablets can be used to add multiple inputs, similar TUI is not confined to visual and auditory senses, but also the sensation of touch. TUI may also have three-dimensional perspectives [29]. Some researchers noticed that this TUI can compensate for the shortcomings of the GUI, but there have other researchers argued that although TUI provides haptic feedback and intuitiveness compared to GUI but lacks in portability and flexibility [5]. Therefore, they have conducted various studies comparing the TUI with the GUI in different aspects. A summary is shown in Table 2.1, collaboration are in **bold** font.

Table 2.1: Summary of previous comparative studies

Authors	**Interfaces**	**Task**	**Measures**	**Findings**
Xie et al. [38]	GUI TUI Physical	Puzzles	Performance Engagement Enjoyment Collaboration	Performance: TUI & Physical Engagement: TUI & Physical Enjoyment: no difference
Horn et al. [10]	GUI TUI	Programming Robot	Performance Engagement Collaboration	Performance: no difference Engagement: no difference
Sapounidis et al. [27]	GUI TUI	Programming Robot	Enjoyment Easy-to-use	Enjoyment: TUI Easy-to-use: TUI
Cheng et al. [5]	GUI TUI	3D learning	Engagement	Engagement: no difference
Almjally et al. [1]	GUI TUI	Programming	Performance Attitude Enjoyment	Performance: GUI Attitude: TUI Enjoyment: no difference

Xie et al. [38] compared pairs of children playing puzzles between three different interface styles (physical, GUI, TUI). The result showed that TUI and physical outperformed GUI in terms of complete-time and engagement, but not in terms of enjoyment. In addition, parallel, independent collaboration strategies in TUI and physical were observed, while in the GUI the children took turns in sequence. Finally, no higher levels of verbal interaction were found in the three interfaces. Horn et al. [10] also conducted a study for comparing TUI and GUI, using a programming language to control a robot in a museum. They found that TUI promoted more active collaboration and was more child-focused than GUI. However, the opposite finding to Xie emerged in terms of performance and engagement. Sapounidis and Demetriadis [27] also conducted a study between GUI and TUI for three different age groups of children to program a robot. The results indicated that TUI was more enjoyable and easier to use for younger children.

In addition to comparing in the collaborative setting, some non-collaboration studies were also conducted. Cheng et al. [5] compared GUI and TUI for primary school students with no prior computing experience to promote 3D learning. It found no significant differences in engagement between these two interfaces. However, the importance of prior experience was highlighted and the idea that prior experience is one of the most important factors in assessing performance was mentioned. Finally, Almjally et al. [1] conducted another comparative study of the GUI and TUI to support the teaching of programming to children. The results indicated that GUI was better than TUI in terms of performance, but the TUI showed a greater improvement in attitude.

In summary, the use of different settings and implementation of different environments led to these conflicting results. Although some were designed for collaborative activities, none of the participants was assigned roles by the experimenter, and no codependent access points were built, thus leading to a negative collaboration, such as parallel, independent collaboration. Furthermore, the most critical element of collaboration – positive interdependence – was not mentioned, and none of these studies compared different interfaces in terms of supporting positive interdependence.

3 Research Questions

My thesis focused on the difference between GUI and TUI in supporting positive goal interdependence which is a key element for collaborative learning. As in section 2 pointed out that compared with traditional interfaces (GUI), TUIs have so many benefits, but it is still not clear in which areas TUIs exactly do better work in terms of supporting positive goal interdependence. Therefore, my thesis aims to explore the following threes research questions:

- ***RQ1:*** *How can tangible interaction support positive goal interdependence in the collaborative activity for children?*
- ***RQ2:*** *What are the differences between GUI and TUI to support such positive goal interdependence for children? Do TUIs outperform GUIs?*
  - ***RQ2.1:*** *What are the differences about their collaboration?*
  - ***RQ2.2:*** *What are the differences about their learning performance?*
- ***RQ3:*** *Can TUI make children more enjoyable and engaged than GUI?*

4 Prototype Design

4.1 Concept Ideas

4.1.1 Interdependent Interaction

According to the literature review [35, 6], several key factors are needed for creating a positive goal interdependence.

A scenario is needed where children can rely on each other, immerse themselves and have fun. It is well known that playing games are natural and favourite activity for children. After investigating the current games played by children, I found a traditional and easy-understanding game called “Maze”. Maze starts from ancient Greek culture and continues to today. As shown in the Figure 4.1, the open-world action-adventure game “Zelda breath of the wild”, released in 2017, and the simulation role-playing game “Stardew Valley”, released in 2016, both add elements of mazes. As a child-friendly and concentration-enhancing game scenario, we choose the maze as our collaborative scenario.

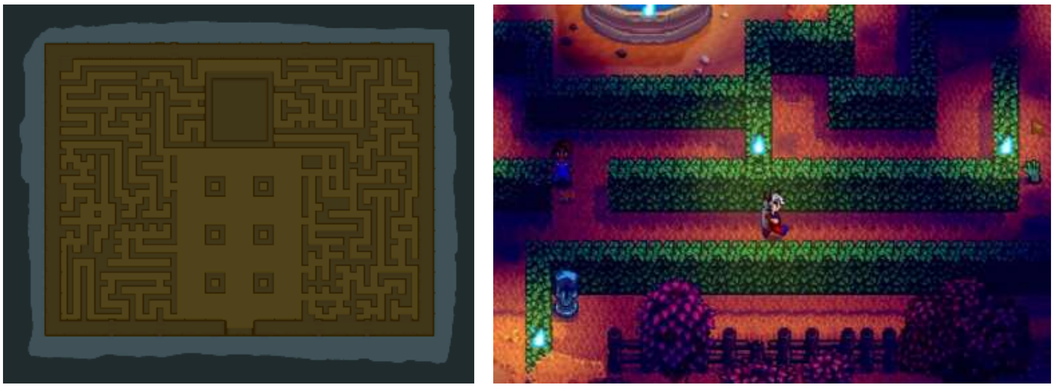

Figure 4.1: Maze in the switch game “Zelda breath of the wild” and “Stardew Valley”

Assignment, role distribution and **a clear group goal** are important elements of positive interdependence. Roles are allocated in line with specific responsibilities, which engages learners and allows them to truly adopt the challenge of unique ownerships and responsibilities [36, 6]. According to the literature review [12], a powerful way to create positive interdependence in a collaborative environment is to distribute information, skills, roles or tools among learners so that they can work together to achieve success. For example, in the jigsaw puzzle game, many children work in parallel, with one starting from the top and the other from the bottom, which implies a divide-and-conquer strategy [38].

I built a collaborative maze game where the children were “forced” to work together on a natural occasion. It requires the active and equal participation of both children to create positive interdependence. The movement of the game character is divided between two children, where one child controls the horizontal movement and the other is responsible for the vertical one, as shown in the Figure 4.2. In order to move this game character, both children should collaborate and rely on each other. The goal is also clear, where two children have to work together and find the exit.

Negotiation is required to give children opportunities to communicate and exchange ideas. Therefore, I added some gamified elements. In my *CollabMaze*, children need to collect enough coins, a key and killing monsters in order to open the exit door. In addition, I designed two exits for the maze, which means that children need to negotiate to decide a correct walking path.

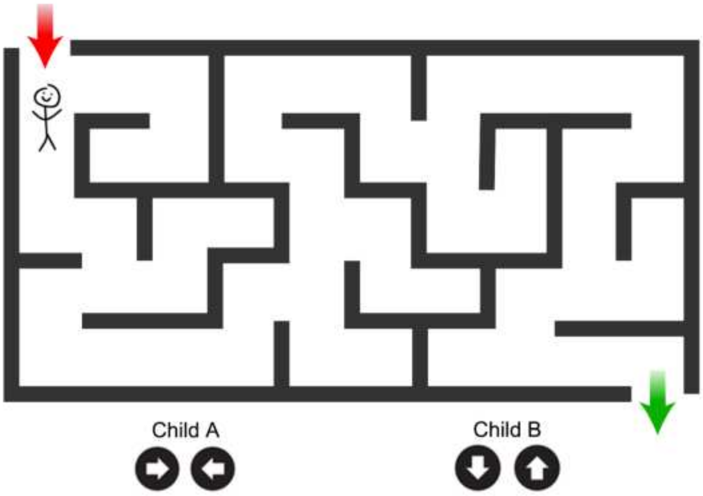

Figure 4.2: Divided movement

4.1.2 Goal Interdependent Task

Papar Prototype Before building the final technical prototype, a paper prototype was created. The main purpose of the paper prototype was to determine the difficulty of the maze for the children. Because if the maze is too difficult, children would be discouraged and lose their confidence. In contrast, if it is too easy, they would be able to find an exit without much communication and negotiation.

I used 6 mazes with different sizes and shapes. The detailed parameters are as following:

1) *20*10 orthogonal maze with one exit*
2) *25*15 orthogonal maze with two exits*
3) *30*20 orthogonal maze with two exits*
4) *40*30 orthogonal maze with two exits*
5) *25 cells circular maze with two exits*
6) *15 cells circular maze with one exit*

The structure of the maze was randomly generated from a maze generator website [1]. I defined the size and location of the exits. It was randomly generated mazes, which only has one exit. Therefore, I modified this maze design and added one more exit.

Paper Prototype Study One 6-year-old girl and one 5-year-old boy participated in my paper prototype study, which took place indoors and lasted for around 30 mins. I asked these two children and their parents if they knew what a maze was and if they had ever played one. They answered that they played, but it was a simple maze with the illustrations, not a maze with only black and white lines and without any cartoon hints. Six mazes were given to them, and they were asked to draw the routes in pencil and complete them independently, starting with the easiest maze and following the sequence from 1 to 6. For the first four orthogonal mazes, they took different amounts of time to finish, where the girl completed them first and helped the boy to complete the

[1] https://www.mazegenerator.net/

40*30 orthogonal maze. For the two circular mazes, both of them had problems, so I helped them. As shown in Figure 4.3 and Figure 4.4, these are the scanned photos of their playing results. After the experiment, they were asked some questions in terms of difficulty and fun for playing these different mazes.

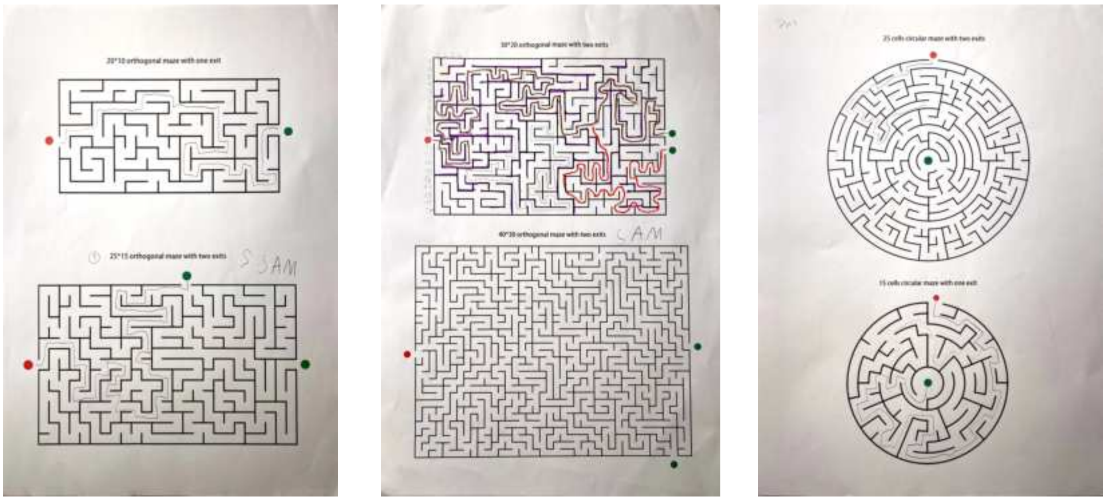

Figure 4.3: Results from the boy's paper prototype

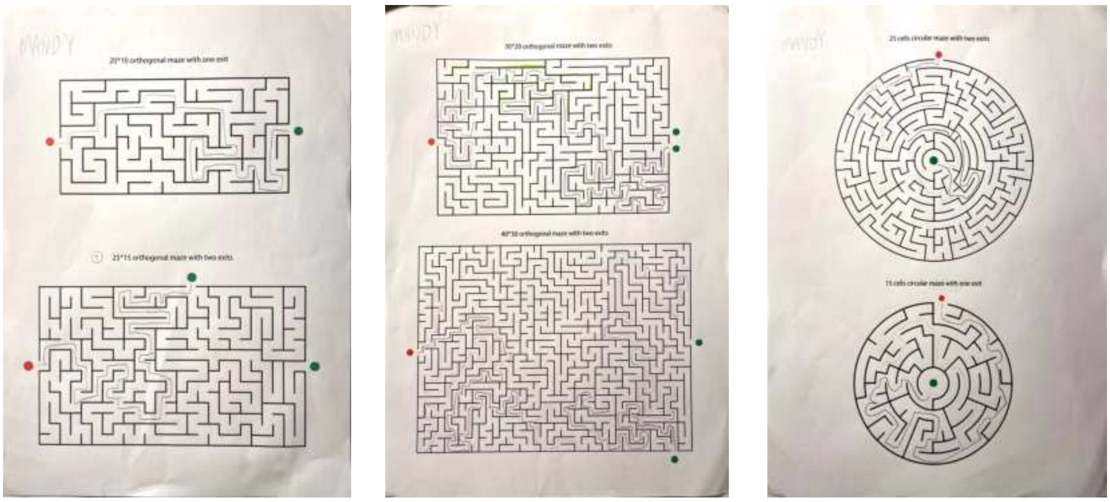

Figure 4.4: Results from the girl's paper prototype

Difficulty of Final Prototype 30*20 orthogonal maze was the most difficult maze, which both children could still manage in the paper prototype study. Therefore, I set this size as a medium level of my final prototype. The reason for not putting this size at the most difficult level is that on the one hand collaborative work would facilitate task completion and promote motivation and patience, so it might be easier for two children to solve the mazes together. On the other hand, we might have a bit older children to participate in the final user study. As a result, the width and height of the mazes conform to the linear function

$$\textbf{height} = \tfrac{2}{3}\ \textbf{width}$$

as shown in the Figure 4.5. The exact width and height of the final prototype can be found below:

1) *6*4 orthogonal maze with two exits*

2) *18*12 orthogonal maze with two exits*

3) *30*20 orthogonal maze with two exits*

4) *42*28 orthogonal maze with two exits*

5) *54*36 orthogonal maze with two exits*

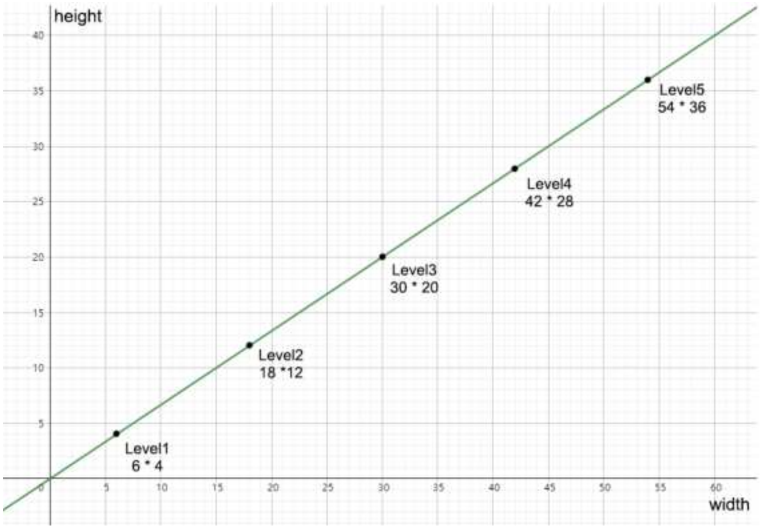

Figure 4.5: The linear function of mazes' size

4.2 Goal Interdependent Maze

The prototype design has two parts: one is the digital maze (i.e., GUI), the other is the tangible controller. The digital maze was run on an iPad and was made with Unity with the version 2019.3.15f1. First, the children can choose their own character from three avatars (see Figure 4.6).

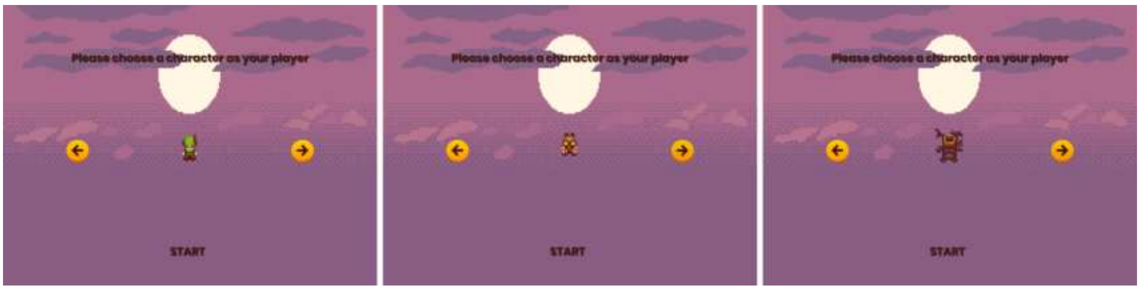

Figure 4.6: GUI: Character selection

After selecting an avatar, they need to choose a maze from 6 options with a teaching demo (see Figure 4.7). The teaching demo is a setting in which the character can move around without obstacles, i.e., no mazes or walls in this space. It contains all the elements of the game: monsters, coins and keys, as well as the start and endpoints. At the bottom, I designed two sets of control buttons, consisting of up-down buttons and an attack button (star). In the middle is an area displaying information of collected and need-to-be collected coin numbers, as well as the current status of the keys obtained. The red wall, in the end, will be opened automatically only when enough gold coins and keys have been collected. There is no such compulsory requirement regarding monsters, but in the regular levels, the monsters will block the path and do not allow the player to pass. So the children are forced to kill it to get through. After they reach the destination (pictorial trophy), the “You did it” screen is presented, providing the total time spent and the walking time.

Figure 4.7: GUI: Level selection, Teaching Level, “You did it” screen

As mentioned in the concept idea, the two exits are designed as a stimulus for negotiation, as we can see in the Figure 4.8 and Figure 4.9. As the difficulty increases, not only the maze size increases but also the number of coins and monsters that need to be solved. In addition, the location of these collected items is not far from the solution path.

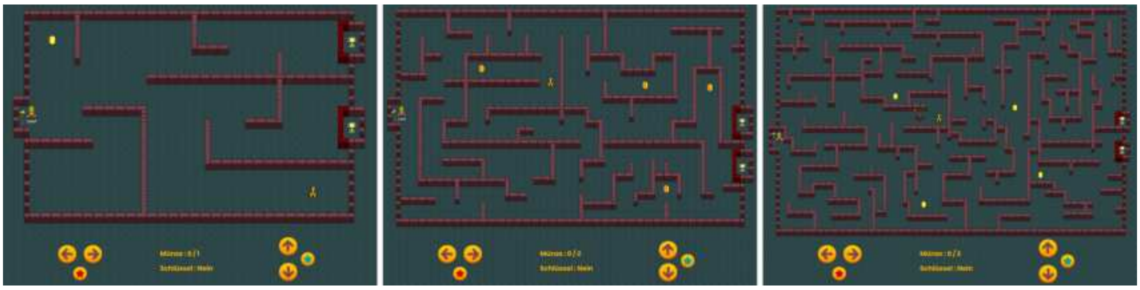

Figure 4.8: GUI: Level1, Level2, Level3

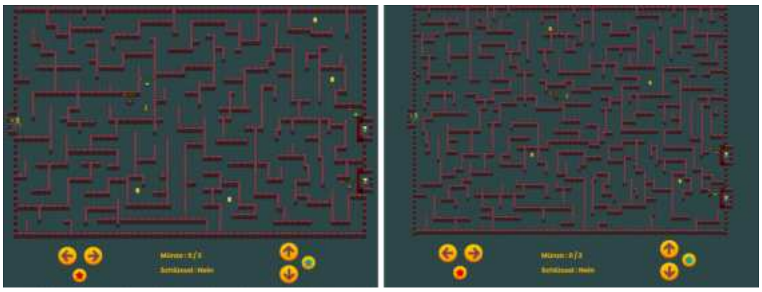

Figure 4.9: GUI: Level4, Level5

4.3 Tangible Controller

My hardware development had two main components: two joysticks and a base box.

4.3.1 Joysticks

The joystick module that I used was the KY-023 two-axis analog joystick with a size of 4 * 2.6 * 3.2 cm (as shown in the Figure 4.10). To accomplish divided movement control, one joystick is designed for up-down movement (y-axis), while the other is for the left-right (x-axis). In order to prevent other directions' movement, as shown in Figure 4.11, I created the wooden rails. By simply moving or pressing the joystick, the children can control the game character left-right, up-down, or beat monsters.

Regarding the five pins of the joystick, from top to bottom they are GND, +5V, VRx, VRy and SW, which correspond to GND, power, x-axis, y-axis, and switch.

- *GND - The ground pin, connected to the GND pin of the Arduino.*
- *+5V - Pin for the power supply, connected to the 5V pin of the Arduino.*
- *VRx - pin for the X-axis of the joystick module, connected to the A0 pin.*
- *VRy - Pin for the Y-axis of the joystick module, connected to the A1 pin.*
- *SW - Pin for the so-called "switch", connected to the 12 or 13 pin.*

Figure 4.10: TUI: size of joystick

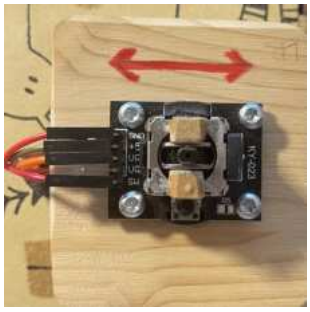

Figure 4.11: TUI: wooden rail

To make it easier to grip the joysticks, I drilled a hole in the middle of the wood as a joystick cap. This makes it more child-friendly. In addition, as the control buttons in the GUI condition cannot be moved and the two sets of buttons are kept at a fixed distance from each other, I also made a wooden joystick base and screwed the joysticks on it, to fix them at the same distance for facilitating a valid comparison (see Figure 4.12). Furthermore, I drew red and blue arrows on the joysticks' bases to simulate the same directional hints on the control buttons in the GUI condition.

Figure 4.12: GUI: same distance of controls between GUI and TUI

4.3.2 Base Box

Two joysticks are fixed on a large base with a size of 25 * 10 * 5 cm, which is a fully closed box made by the laser cutter (see Figure 4.13). The main function of this base box is to hide the wires in the Figure 4.14 and to connect them to the pins of the joysticks through the small holes at the top of the base box. In addition, the Arduino Uno and the bread broad are also hidden in the base box. Moreover, as the planned date for the user study was Christmas, I put wrapping paper painted with deer on all six sides of the base box to attract the children's interest. Finally, I used a USB cable to connect the TUI and GUI to communicate the joystick data to the computer in time and convert it into coordinates for the character movement in the *CollabMaze*.

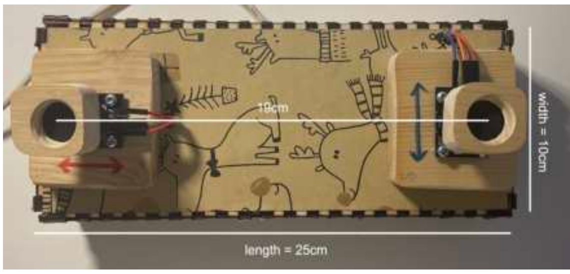

Figure 4.13: GUI setup

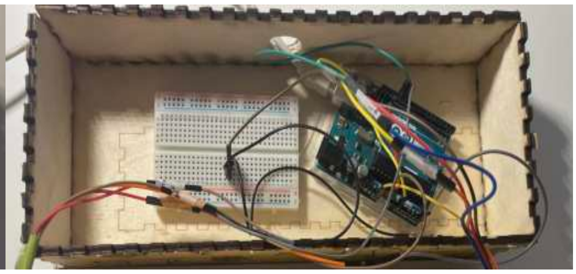

Figure 4.14: TUI setup

5 User Study

5.1 Participants

A total of 20 children (11 boys, 9 girls, 10 pairs with 6 pairs of Chinese, 3 pairs of Chinese-German and 1 pair of German) participated in my user study. I asked the parents the age of their children in advance. Then, I assigned children to GUI or TUI based on their age. For the GUI condition, 3 pairs of boy-girl groups and 1 pair of girl-girl. For the TUI condition, 1 pair of boy-girl, 3 pairs of boy-boy groups and one pair of girl-girl. Most of them were fluent in German or English. In addition, we have eight pairs who were siblings, and the other two pairs were classmates and friends (in TUI condition). The average age of GUI children was 7.5 (SD = 1.84), for TUI was 7.8 (SD = 1.48). Detailed information can be seen in Table 5.1.

Table 5.1: Demographic information of participants

GUI					TUI				
Group	**ID**	**Age**	**Gender**	**Relationship**	**Group**	**ID**	**Age**	**Gender**	**Relationship**
1	1 2	6 6	f m	sibling	1	5 6	7 10	f f	sibling
2	3 4	7 6	f m	sibling	2	9 10	7 8	m m	classmate
3	7 8	10 6	f m	sibling	3	13 14	10 6	f m	sibling
4	11 12	8 10	f m	sibling	4	15 16	6 8	m m	sibling
5	19 20	6 10	f f	friend	5	17 18	7 9	m m	sibling

5.2 Procedure

Because of the influence of Covid-19, all user studies were conducted in the participants' homes. Strict protective measures were taken and the areas that the children touched were disinfected before and after each experiment. I was fully vaccinated twice and had a rapid antigen test before every group in order to protect the health of the children and their parents. For the reliability of the observations, I asked one of my friends to assist me with the observations and to explain the questionnaire to the child separately if necessary.

The experimental time for each user study was about 30 - 45 minutes. In the GUI condition, an iPad Pro with 12.9", resolution 2732 x 2048 px, version 14.8.1 was used to show the game for children (see the Figure 5.1). In the TUI condition, an HP Laptop 17-cb1xxx with a 2.6Ghz Dual-Core Intel Core i7 processor, NVIDIA GeForce RTX 2070, 17.3", resolution of 1920 x 1080 px was connected to the TUI-Prototype as an input device in the Figure 5.2. A smartphone for taking pictures and recording was used for both cases. For collecting the evaluation from children, different measure methods were designed as it can be seen in Table 5.2. Taking into account the fact that children are not familiar with iPads or are not skilled in using a mouse, all questionnaires are printed.

Initially, the children's guardians read the signed consent form and participant information and were given a student code for each child in case they wanted to withdraw the data from the experiment later. All participants were then asked to start with a pre-questionnaire. The questions were asked verbally by the study leader to ensure that every child understand correctly and also to give us a possible opportunity to get acquainted with the child for a subsequent interview session.

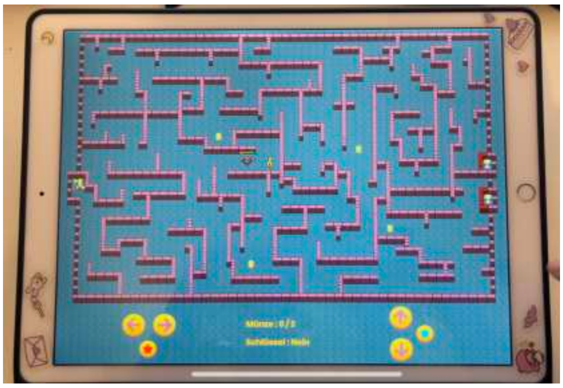

Figure 5.1: GUI setup

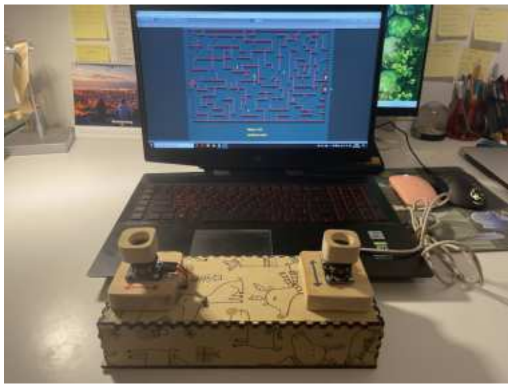

Figure 5.2: TUI setup

The children were then assigned one of two different interface types. Before the game started, they were free to choose one of the three characters they want to manipulate for the whole maze game. Through verbal explanations and a simple tutorial, participants were shown how to play the maze and are told that they need to work in pairs to solve a total of five different mazes of varying difficulty without outside help. The time spent by the children on each maze and the time they spent walking was recorded and the whole game process on the iPad or computer was screen recorded. While the children play with maze game as in Figure 5.3 and Figure 5.4, the behaviours and verbal activities of pairs were observed by two observers, classified and recorded in a prepared observation form. After all five mazes were completed, the participants were asked to complete a paper post-questionnaire consisting of 29 items, during which the study leader verbally explained any vocabulary that the children did not understand to ensure that there were no discrepancies in their understanding of each question. The user study ended with a short, audio-recorded interview consisting of three questions.

Table 5.2: Experimental conditions of GUI and TUI

	GUI	**TUI**
Apparatus	iPad Pro (12.9", 2732 x 2048 px)	HP Laptop 17-cb1xxx (17.3", 1920 x 1080 px) TUI-Prototype
	A smartphone for taking pictures and recording	
Participants	10 (5 pairs)	10 (5 pairs)
Average Time	30min 44sec (7min 19sec)	32min 13sec (6min 54sec)
Location	Indoor	
Evalution	Verbally + Paper questionnaire of 29 items	
Pre-knowledge	Verbally asked by study leader	
Performance	System data (playing time)	
Engagement	System data (walking time / playing time)	
Enjoyment	Post-questionnaire (Intrinsic Motivation Inventory (IMI))	
Interdependence	Post-questionnaire (Social Interdependence Scale)	
Usability	Post-questionnaire (System Usability Scale)	
Collboration	Observation form (recorded from two observers)	
Interview	Verbally asked by study leader	

Figure 5.3: GUI group during user study

Figure 5.4: TUI group during user study

5.3 Evaluation

According to the user study design, several forms of quantitative and qualitative data were collected.

5.3.1 Pre-Post Test

A pre-questionnaire, which was verbally asked by the study leader, was used to obtain participants' demographic information, relationship with their partner, tablets or computers experience, maze experience and interest in the maze game. Experience with a tablet or computer in this context refers to prior experience or knowledge. Familiarity might influence their performance, so we measured children's technology experience.

A paper post-questionnaire was used to measure participants' perceptions of enjoyment, interdependence and usability. The measure I used to measure enjoyment in the user study was the Children Intrinsic Motivation Inventory (IMI) interest/enjoyment scale [26]. It consists of 7 items, from which two are negatively formulated. I continued to use these two reversed items in this my study because I considered that it would be easy for participants to have habitual thinking if they were all positively formulated statements. The Social Interdependence Scales is a five-point Likert Scale for measuring individuals' cooperative, competitive, and individualistic perceptions [15]. I selected 4 items from each subscale that was child-friendly, so it had 12 items. System Usability Scale was used after participants finished their games [24]. It consisted of 10 questions. All items were modified because of the theme of the maze game and translated into German or English for the participants. The Cronbach's alpha, as shown in the Table 5.3 indicated that they all have good reliability.

Table 5.3: Cronbach's alpha

	Cronbach's Alpha
Enjoyment scale	0.812
Social interdependence scale	0.744
Usability scale	0.744

According to this point, a special rating scale based on the Smileyometer which is a 5-point Likert Scale for collecting children's subjective evaluation was used for all these statements [25]. A pictorial representation of five distinct smiling faces from Figure 5.5 is used in my study.

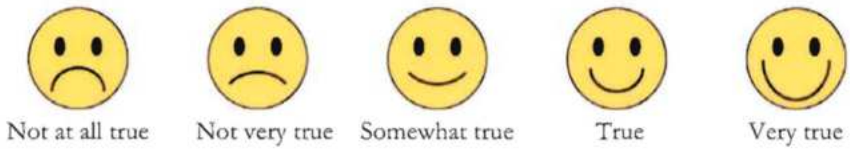

Figure 5.5: Smileyometer Scale

5.3.2 Observation

Two observers were responsible for one child in a group to take the observation forms according to their interaction with them. Specifically, the observation form is made up of several possible behaviours and verbal and facial expressions that I hypothesised before the user study. Two observers were able to infer whether the behaviours fell into one of the four categories of collaboration activities of "non-verbal helping", "verbal helping", "sharing ideas" or "displeasure", based on the specific actions of the participants and their interactions with their peers. The frequency of these four collaboration activities was counted. In order to avoid confusion that could lead to biased data, two observers recorded the behaviours of two children separately, for example, one recorded the child who controlled the up-and-down movement and the other was responsible for the child who controlled the left-right movement. As already mentioned, the behaviours were divided into four categories of collaboration activities:

Non-verbal helping:

- Pointing at the iPad or computer screen
- Gesturing in the air with hand gestures
- Taking his/her partner's hand to help with the operating
- Directly pushing away his/her partner's hand or body to gain control of from him/her

Verbal helping:

- Talking to each other such as "upwards"

Sharing ideas:

- Talking to each other such as "Let's take this way to get the coin"

Displeasure:

- Talking to each other such as "You are stupid!"
- Unhappy facial expressions such as frowning or pouting

5.3.3 Interview

In the end, I finished the user study with three open-ended questions related to their experience and advice about the maze game. With the consent of their parents, the playing session and the communication of the interview session were audio-recorded to be able to have better evaluation reviews after finishing all user studies and make a transcript for specific time points.

- Do you have some advice about the game or joystick?
- Which part do you like at most?
- Have you ever helped your partner during the maze game?

5.3.4 System Data

I noted the total duration of each pair's maze play and the walking time of each level from the start point to the destination to measure the performance and engagement as system data.

6 Results

6.1 System Usability

To calculate the SUS score from the processes provided in [4], the odd-numbered statements have positive meanings, whereas the even-numbered statements have reversed meanings. Thus, statements with opposite meanings are handled differently. For example, for the positive meaning, a normalized score is obtained by subtracting 1 from the participant's score (x-1), but for the negative meaning, the participant's score is subtracted from 5 (5-x). These normalized scores are then added together and multiplied by 2.5 to give a final score ranging from 0 to 100. For each GUI and TUI interface type, average SUS scores are calculated as shown in Table 6.1 and Table 6.1.

Then average SUS for the five pairs in the GUI condition was 66.25 (*SD* = 16.68), whereas in the TUI condition was 82.75 (*SD* = 9.24). These results show that TUI has better usability than GUI. Moreover, average SUS scores of each interface style are higher than 65, so they are all acceptable in terms of usability [3].

Table 6.1: Mean SUS score

Interface Type	N	Mean (*SD*)
GUI	10	66.25 (16.68)
TUI	10	82.75 (9.24)

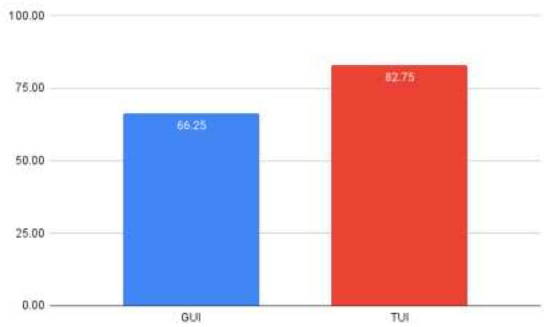

Figure 6.1: Mean SUS score

6.2 Previous Technoloy Use Experience

The results of the pre-questionnaire are shown in the Table 6.2, it contains maze game experience, tablet and computer experience and interest in maze games. All GUI children had played the maze, but one of the TUI children in the second group (T2) had not. As shown in Figure 6.2, most of the children had used a tablet or a computer. Eighty percent of the GUI players used the tablet or computer at least once a week, either for online classes or to play games and watch videos. The remaining 20% of children had no experience. Twenty pecent of TUI players used the tablet or computer daily, 30% indicated that used weekly, 30% used monthly and the other 20% hardly ever used.

Furthermore, according to the 5-point Smileyometer scale, the average interest in the maze game was obtained, with the GUI groups showing a slightly higher interest than the TUI groups. The average interest in the maze game of the GUI groups was 4.2 (*SD* = 0.79), similar to 4.11 (*SD* = 0.6) for the TUI groups. Basically, the children of both groups rated a score of 3 or more, with a majority of 4 and 5. The specific distribution of children's interest in the maze can be seen in Figure 6.3.

Table 6.2: Results of Pre-questionnaire

Pre-Questionaire question		**GUI**	**TUI**
Have you ever done a maze before?	Yes	100%	90%
How often do you use the tablet or computer at your home or your school?	none	20%	20%
	monthly	0%	30%
	weekly	80%	30%
	daily	0%	20%
I like doing mazes.	3	20%	10%
	4	40%	60%
	5	40%	20%

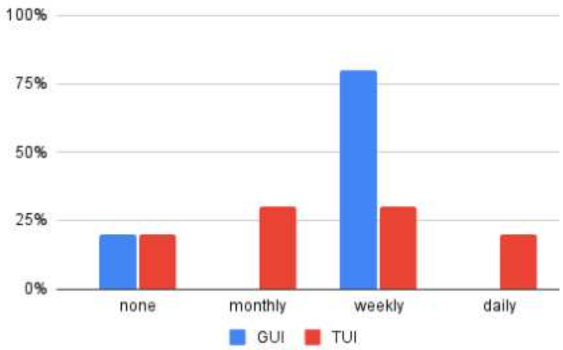

Figure 6.2: Tablets or computers experience

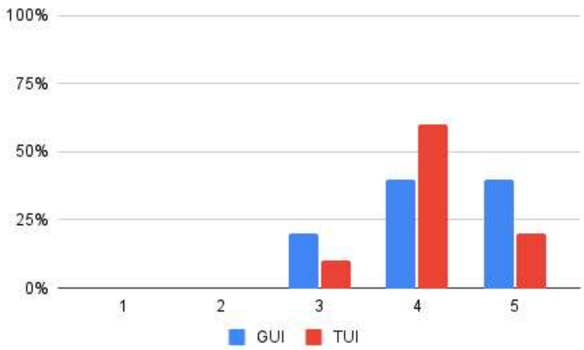

Figure 6.3: Interest in maze game

6.3 Collaborative Interdependence

In my study collaboration, performance and usability were used to investigate the differences between GUI and TUI to support positive goal interdependence for children. The results of the questionnaire and in-field observations are compared to answer research question ***RQ2.1***.

Cooperative, competitive and individualistic interdependence were assessed by the Social Interdependence Scale (SIS) which includes two parts regarding like to cooperate/compete/study alone, and valuing cooperative/competitive/individualistic learning [15]. Means and standard deviations (*SD*) for three subscales are shown in Table 6.3. As seen in Figure 6.4, cooperation has the highest mean score, followed by the competition, and finally the individualistic. Based on the *t*-test, the difference between the GUI and TUI was not significant.

Table 6.3: Mean SIS scores of three subscales

	Interface Type	**N**	**Mean (*SD*)**	***t*-test**
Cooperative interdependence	GUI	10	4.3 (0.56)	*t = 0.83*
	TUI	10	4.08 (0.65)	
Competitive interdependence	GUI	10	3.58 (1.2)	*t = 1.029*
	TUI	10	3.08 (0.96)	
Individualistic interdependence	GUI	10	2.6 (0.65)	*t = 0.626*
	TUI	10	2.4 (0.77)	

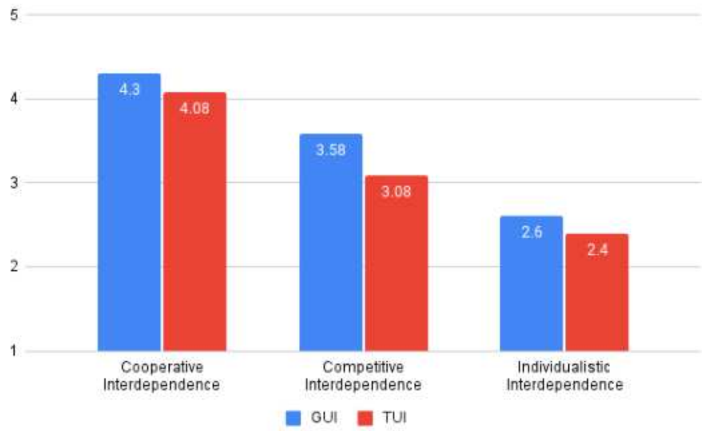

Figure 6.4: Mean SIS scores of three subscales

Because the importance of the prior knowledge is mentioned in the related work [5], I compared the difference of TUI and GUI on interdependence when children normally use electronics with the same frequency. As seen from Table 6.4 and Table 6.5, TUI and GUI interfaces provided the same cooperation, whereas the GUI interface was marginally more competitive than the TUI. However, there was no difference between GUI and TUI in terms of cooperative and competitive interdependence for children who used electronics weekly and for those who never used them (two-tailed t-test). Finally, TUI showed more individual than the GUI for children who used electronics weekly, there was a significant difference between GUI and TUI in terms of individualistic interdependence (two-tailed t-test, $p* = 0.036 < 0.05$), but for children who never used them, this difference was not found.

Table 6.4: Weekly prior experience compared to SIS scores

	Interface Type	N	Mean (*SD*)	*t*-test
Cooperative interdependence	GUI	8	4.34 (0.53)	$t = 0.028$
	TUI	3	4.33 (0.58)	
Competitive interdependence	GUI	8	3.38 (1.26)	$t = 0.776$
	TUI	3	2.75 (0.9)	
Individualistic interdependence	GUI	8	2.38 (0.42)	$t = -2.455$
	TUI	3	3.17 (0.63)	$p* = 0.036$

Table 6.5: No prior experience compared to SIS scores

	Interface Type	N	Mean (*SD*)	*t*-test
Cooperative interdependence	GUI	2	4.13 (0.88)	$t = 0$
	TUI	2	4.13 (1.24)	
Competitive interdependence	GUI	2	4.38 (0.53)	$t = 0.59$
	TUI	2	3.75 (1.41)	
Individualistic interdependence	GUI	2	3.5 (0.71)	$t = 1.41$
	TUI	2	2.5 (0.71)	

6.4 Enjoyment

The scores of the two negatively formulated items should first be subtracted from 8 to obtain the opposite score [26]. The final score was then calculated by averaging all items as shown in Table 6.6. As a result, the mean enjoyment score of GUI groups was 4.24 (*SD* = 0.57), and the mean score of TUI groups was 4.17 (*SD* = 0.65). *t*-test results show that they have no significance (two-tailed *t*-test, $p = 0.799 > 0.05$).

Table 6.6: Mean IMI scores

Interface Type	N	Mean (*SD*)	*t*-test
GUI	10	4.24 (0.57)	*t = 0.259*
TUI	10	4.17 (0.65)	

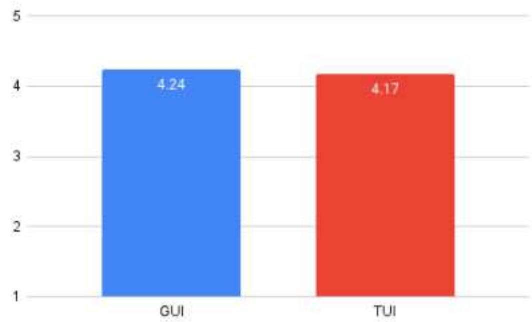

Figure 6.5: Mean IMI scores

As seen from Figure 6.7, TUI interface was marginally more enjoyable than the GUI for (1) children who did not use tablets and computers much and (2) those who used them weekly. However, according to the *t*-test shown in Figure 6.8 and Figure 6.7, there was no difference between GUI and TUI in terms of enjoyment for children who used electronics weekly (two-tailed *t*-test, $p = 0.87 > 0.05$) and for those who never used them (two-tailed *t*-test, $p = 0.913 > 0.05$).

Figure 6.6: Frequency of tablets or computers use compared to IMI scores

Interface Type	N	Mean (*SD*)	*t*-test
GUI	2	4.36 (0.3)	*t*= -0.123
TUI	2	4.43 (0.81)	

Table 6.7: None

Interface Type	N	Mean (*SD*)	*t*-test
GUI	8	4.21 (0.63)	*t*= -0.168
TUI	3	4.28 (0.52)	

Table 6.8: Weekly

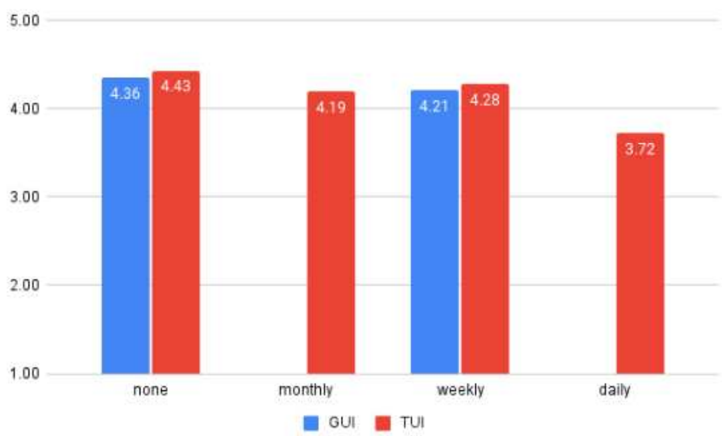

Figure 6.7: Frequency of tablet or computer use compared to enjoyment

6.5 Engagement

6.5.1 General Engagement

The walking time of the character was used to compare engagement between two TUI and GUI. The total game time contains character walking (i.e., playing) time and communicating and helping time. Walking time and playing time were both system data, where walking time recorded the total time the character has been walking, i.e. the time the character has been stationary in place is not recorded. Engagement is equal to walking time divided by playing time, meaning the percentage of walking time in the playing time.

$$Engagement = \frac{Walking\ time}{Playing\ time}$$

As a result, for the entire maze game, the walking time of the TUI interface accounted for 59.42% of the playing time, whereas the GUI only accounted for 43.8% (see Table 6.9 and Table 6.8).

Table 6.9: Mean engagement for GUI and TUI

Interface Type	N	Mean (*SD*)
GUI	10	43.8% (8.18%)
TUI	10	59.42% (5.56%)

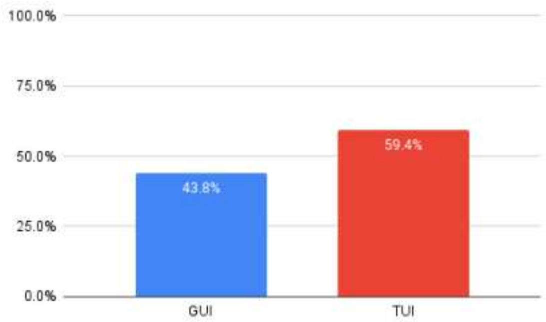

Figure 6.8: Mean engagement for GUI and TUI

6.5.2 Engagement for Each Game Level

The Figure 6.9 shows the average percentage of walking time to total playing time for each level and for the entire game on GUI and TUI. In each level, the ratio of walking time was higher for children using the TUI interface than for those using the GUI. This demonstrates that the TUI is better at supporting positive interdependence than the GUI in terms of engagement. However, as children's playing time increases, in the case of the GUI, walking time as a percentage of playing time tends to increase, becoming close to the TUI from Level 3 onwards.

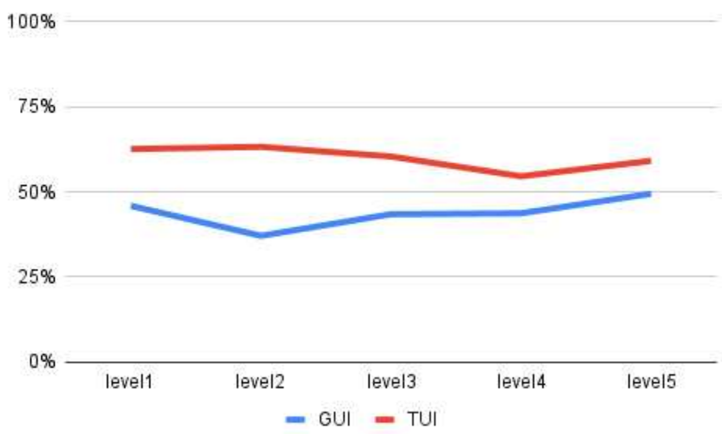

Figure 6.9: Mean Engagement for different levels

Because the importance of the prior knowledge is mentioned in the related work [5], I compared the difference of TUI and GUI on engagement when children normally use electronics with the same frequency. As seen from Figure 6.10, children with the same prior technology experience engaged more in the TUI condition than those in the GUI.

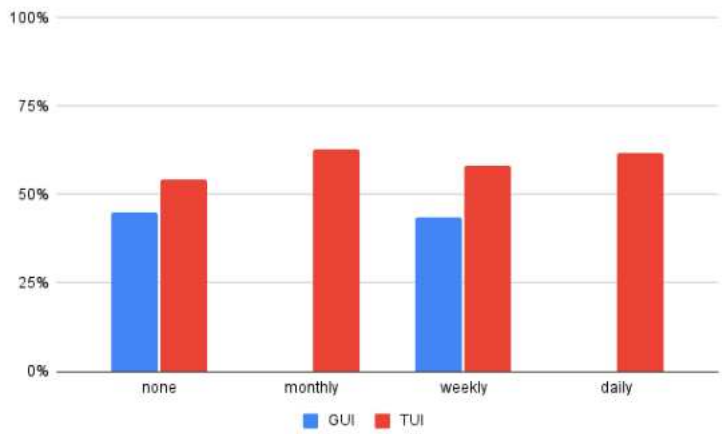

Figure 6.10: Frequency of tablets or computers use compared to engagement

6.6 Performance

6.6.1 Total Playing Time

The overall maze playing time from the first to the fifth level was recorded by the system. The average playing for GUI pairs was 17min12sec (*SD* = 5min45sec) (see Table 6.10 and Table 6.11), whereas TUI were 11min54sec (*SD* = 3min10sec).

Table 6.10: Mean playing time for GUI and TUI

Interface Type	N	Mean (*SD*)
GUI	10	17min12sec (5min45sec)
TUI	10	11min54sec (3min10sec)

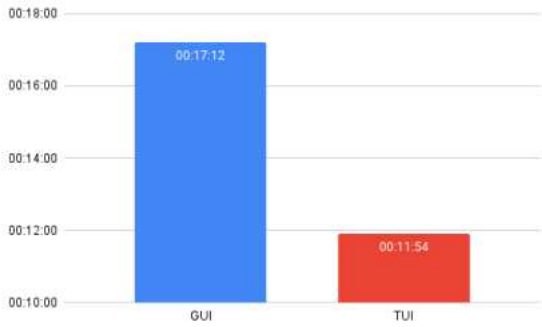

Figure 6.11: Mean playing time for GUI and TUI

6.6.2 Playing Time for Each Game Level

The mean time in the maze game increased gradually from Level 1 to Level 5, due to the increase in difficulty and size of the maze. As seen in Figure 6.12, the mean time spent on each level for TUI was less than for GUI, even for Level 1, where the children were just getting started and needed to get familiar with the interaction. The overall trend in time spent per level for the TUI was slow to increase with no abrupt changes, However, for GUI, the playing time dropped considerably from Level 3.

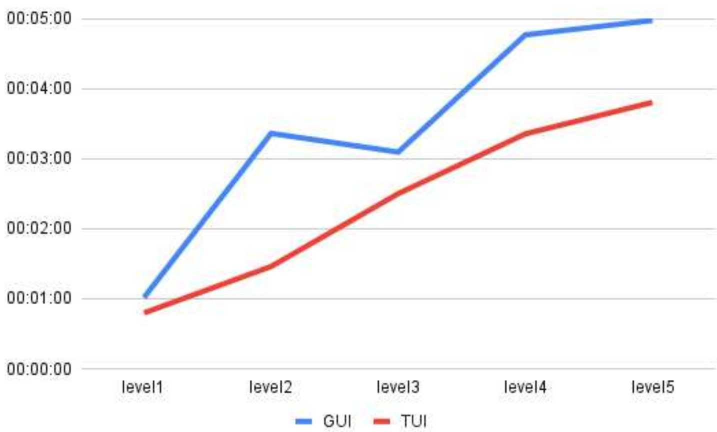

Figure 6.12: Mean playing time for five levels

Based on the literature review [5], considering that playing time may be related to the children's pre-knowledge. Thus, I considered the data from subsection 6.2 for analysis. It can be seen from Figure 6.13, children with the same prior technology experience took less time to complete the game in the TUI condition than those in the GUI.

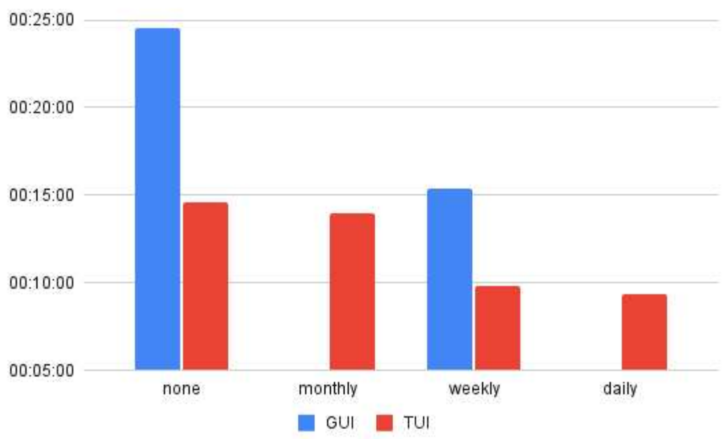

Figure 6.13: Frequency of tablets or computers use compared to playing time

6.7 Observation Results

In order to quantify the observation data during the user study, I counted the frequency of different behaviours from four categories of collaboration activities: “non-verbal helping”, “verbal helping”, “sharing ideas” and “displeasure”. The purpose of quantifying observation data is to compare the GUI and TUI groups more precisely in different dimensions, not simply to express the results in words without evidence. Based on audio transcripts, the example sentences from these four categories are listed in the Table 6.11.

Table 6.11: Example sentences of the audio transcripts

Non-verbal helping
Child A pointed directly on the screen which direction Child B should go. *Child A pointed with his index finger in the air in different directions.* *Child A reached out directly to help Child B control.*
Verbal helping
“Upward...No, go down!” *“Get a little closer.”* *“Go and get it!”* *“Go here.” (with gesture or pointing)*
Sharing ideas
“We should go like this, like this, like this.” (while pointing the way on the screen) *“This way is much shorter.”* *“We should get the key first and then go to the coins here.”* *“We should go this way.”* *“Let’s take this easier for now.”* *“We have to beat these two now, do we beat this one first, then this one, or do we beat this one first”*
Displeasure
“Hey, where are you going?” (Loud talking) *“Oops, what are you doing? Hurry up and get down!” (Loud talking)* *Child B hit Child A’s hand which try to grab the control from B*

6.7.1 General Collaboration Behaviours

In the user study, I found that although all children were focused on completing the game, their frequency of communication differed significantly. The total number of all behaviours per child in the GUI and TUI groups were added together, as seen in Table 6.12 and Figure 6.14. The mean frequency of behaviour per child from TUI groups was 39.5, while it was 35.7 for the GUI group. Furthermore, it was noticeable that the participants shared their ideas significantly more often in the TUI interface than in the GUI, with almost twice the difference.

Table 6.12: Mean frequency of behaviour per child

Collaboration activities		GUI	TUI
Non-verbal helping		**14.8**	**12.2**
1	*Pointing at the iPad or computer screen*	7.3	6.3
2	*Gesturing in the air with hand gestures*	3.4	2.3
3	*Taking his/her partner's hand to help with the operating*	3.2	2.6
4	*Directly pushing away his/her partner's hand or body to gain control of from him/her*	0.9	1
Verbal helping		**12.8**	**10.1**
5	*Talking to each other such as "upwards"*	12.8	10.1
Sharing ideas		**7.9**	**16.2**
6	*Talking to each other such as "Let's take this way to get the coin"*	7.9	16.2
Displeasure		**0.2**	**1**
7	*Talking to each other such as "You are stupid!"*	0.2	1
8	*Unhappy facial expressions such as frowning or pouting*	-	-
Sum		**35.7**	**39.5**

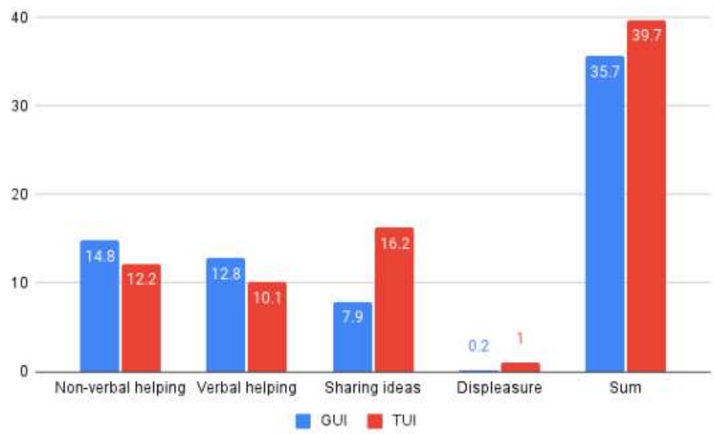

Figure 6.14: Mean frequency of behaviour per child

6.7.2 Non-verbal and Verbal Behaviours

I summarized "non-verbal" and "verbal" behaviours. The average frequency of each non-verbal and verbal behaviours for each child was recorded in Table 6.13 and Figure 6.15. The results demonstrate that the average frequency of non-verbal behaviours per child is higher in GUI than in TUI, whereas verbal behaviours are higher in TUI than in GUI.

Table 6.13: Mean frequency of each non-verbal and verbal behaviours per child

Collaboration activities		GUI	TUI
Non-verbal behaviours		**14.8**	**12.2**
1	*Pointing at the iPad or computer screen **(Helping)***	7.3	6.3
2	*Gesturing in the air with hand gestures **(Helping)***	3.4	2.3
3	*Taking his/her partner's hand to help with the operating **(Helping)***	3.2	2.6
4	*Directly pushing away his/her partner's hand or body to gain control of from him/her **(Helping)***	0.9	1
5	*Unhappy facial expressions such as frowning or pouting **(Displeasure)***	-	-
Verbal behaviours		**20.9**	**27.3**
1	*Talking to each other such as "upwards" **(Helping)***	12.8	10.1
2	*Talking to each other such as "Let's take this way to get the coin" **(Sharing Ideas)***	7.9	16.2
3	*Talking to each other such as "You are stupid!" **(Displeasure)***	0.2	1

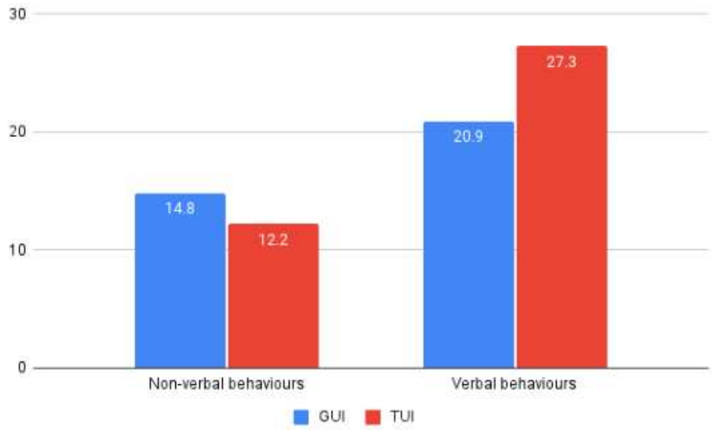

Figure 6.15: Mean frequency of each non-verbal and verbal behaviours per child

6.8 Interview Results

We interviewed three questions in their groups. Given the age of the children, most of the questions were designed as yes/no questions or choice questions. After they had answered "yes" or "no", I asked additional "why" and "how" questions to try to elicit an explanation from them. Nevertheless, I found that most of the children were too shy to talk to strangers. Only when hir or her peer expressed ideas, the shy child tried to communicate with me. The results of the interview questions can be seen in Table 6.14.

When answering *Which part do you like most?*, fighting the monsters was the most common answer, then it was finding the way through the maze. All of the children clearly indicated that they had helped each other during the game and when I asked them how they had helped, some of the children gave examples such as "saying go down or down" or "it's shorter to go here". In terms of providing advice for improvement, 7 children in both cases said that more levels, coins, monsters, and even backgrounds could be added to make it more challenging. Surprisingly, the children with ID 11 and ID 14 independently mentioned the possibility of designing a feature that would allow monsters to move and even attack the character.

Table 6.14: Results of the interview questions

Interview Questions		**GUI**	**TUI**
Do you have some advice about the game or joystick?	Yes	37.5%	60%
Which part do you like most?	Monster	60%	40%
	Finding way	40%	20%
	Collecting coins/key	0%	10%
	All	0%	30%
Have you ever helped your partner during the maze game?	Yes	100%	100%

7 Discussion

7.1 Different Strategies for Collaboration

For ***RQ2***, it will be analysed the difference of performance and collaboration. The results regarding collaboration include quantitative data of observation and the social interdependence scale, as well as qualitative data of interview results. I observed different collaboration styles used by children. The observation data indicated that children in the GUI condition mostly used non-verbal behaviours, while TUI children preferred to use verbal behaviours. It might be because children who used the TUI joysticks as the input device to complete the *CollabMaze* were more possessive. In other words, they did not want their joysticks to be grabbed by their peer, thus verbal communication was especially common in TUI's collaboration. Table 6.13 shows that the reason for the different frequency of verbal behaviours between the two interfaces is due to the different frequency of sharing ideas. This finding supports the assumption that TUIs facilitate children to actively communicate their ideas in the situation of positive interdependence.

However, the analysis results of the social interdependence scale reveal that no significant differences were found. Interview results show that all children explicitly indicated that they had helped each other, but when I asked specifically what they had done, most of the children were unable to explain. I found that in most cases the older children played the dominant roles in the group. When there was a large age difference between two children in a group, the leading child usually does not share ideas with his partner. Once the leading child has found the correct exit path, he will directly verbally command the other child to follow his ideas, for example: "to the left" or "right!". Such behaviour can make the other child very passive, just mechanically following the dominant child's words and being less involved in the game. In summary, the different ways in which children solved the maze task in a collaborative environment between GUI and TUI interfaces were found.

7.2 TUI Took Less Time Might for Better Affordance

As the results in subsection 6.6 show, in the TUI condition children took less time to reach the exit than GUI, for both the whole maze game and each game level. The reason for the longer time in the GUI condition probably is that the contrast between the larger game screen and the smaller control buttons caused players to click on the wrong buttons or miss them when concentrating on the screen. Because for the GUI there is no tactile feedback from pressing virtual buttons, participants clicking on a button or tapping anywhere else on the tablet screen has the same bland feeling. In contrast in the case of the TUI, children do not need to glance down at the joysticks while looking at the screen, which saves a lot of time during manipulation. Children can clearly perceive the feedback by interacting with the physical object.

In addition, there is another important difference in my design between these two interaction modalities. In the GUI condition, up, down (left and right) and shooting are controlled by three different buttons, whereas in the TUI interface, the three different located buttons in the GUI are replaced by moving a single joystick up and down (left and right) and pressing it down. So, for most children, the TUI's joystick can be fully controlled with one hand, whereas the GUI's three buttons need to be controlled with two hands at the same time. As a result, the TUI's design has a better affordance.

7.3 High Engagement, Enjoyment and Interdependence for Both Interfaces

As the results in subsection 6.5 show, the TUI interface has a better effect on children's engagement. From Table 6.8, we can see that TUI children have a stable and better engagement than the GUI at Level 1. From Level 3, there is a noticeable decrease in the engagement between TUI and GUI, and at Level 5 the difference is the smallest. As there are no more levels in *CollabMaze*, it is impossible to see the subsequent development of the children's engagement in both interfaces. In summary, we could find GUI children need time to get familiar with the prototype. TUI is more suitable for children with no prior experience. They can get acquainted quickly in a short period and have a better engagement. Results of enjoyment in Table 6.6 show there is no difference of enjoyment, both are high but similar. In conclusion, TUIs do facilitate high engagement and enjoyment for children but there is no evident difference.

According to the results in Table 6.6, the mean enjoyment scores of both GUI and TUI interaction types are above 4. However, there is no difference. During the interview, the majority of the children from both interfaces said that shooting the monsters was their favourite part of the whole game, even more than finding the right way through the maze. Moreover, based on my observations, when they were confronted by monsters, they became more emotional and talkative. There was even one group that preferred counting the number of monsters and finding their positions first, rather than finding the correct path, when they started a new level. Another group liked to kill all the monsters in the maze before evacuating, even if those monsters were out of the way. Therefore, gamified elements are important for children's enjoyment.

The results of the high cooperative interdependence score and the lower competitive and individualistic interdependence in the Table 6.3 show that both interface types have high interdependence. Although it did appear from the observation results that there were cases where the dominant child directly pushed away or took the other child's hand to help with manipulation, the frequency of these events was minimal. Most of the time, the two children helped and interacted with each other in a non-forced manner. Furthermore, the interview results showed all children knew that this maze task required them to collaborate and that they were interdependent. All the children had helped each other in the maze in their ways. These results demonstrate that design and distributed tasks of *CollabMaze* support codependent relationships and positive goal interdependence to some extent.

7.4 Less Technology Use Experience Required for TUI

Before starting the game, I asked the children and their parents about the frequency of their usual tablet or computer use. The results of frequency were compared with the results of performance, engagement, enjoyment. There were no special findings for enjoyment, but some interesting results were found for the other two elements. For the children's playtime in the maze, under the same background conditions, the TUI interface was used by the children for less time compared to the GUI. However, children who hardly used electronics spent less time in the TUI condition compared to children who used electronics weekly in the GUI condition. The same was found to be true in engagement, with children who barely used electronics in the TUI group having higher engagement compared to children in the GUI group who used electronics weekly. The above results suggest that the TUI interface is suitable and friendly for children without technology use knowledge.

8 Conclusion

In this thesis, a maze game called *CollabMaze* for school-aged children was designed. It derived from a concept idea to a usable prototype in the GUI and TUI condition to support positive goal interdependence. The purpose of my work was to find out the different behaviours and collaborations between two interface styles. The children need to use different inputs devices to collaboratively control the character to escape from the maze, one child controls walking left and right and the other controls walking up and down. In order to create more negotiation of communication, I added some events like collecting a key and enough coins, killing monsters in the way and also two exits that need the children to decide.

A paper prototype study was to determine the difficulty of the maze including the size and shape. For the final user study, I recruited 20 children aged six to ten years in 10 groups, with 5 groups completing the GUI maze and 5 groups completing the TUI maze, as a comparative study. Participants need to complete all 5 levels of the maze game and actively share their ideas. They are codependent. Before the playing, the demographic information and pre-knowledge were collected. During the playing, two observers recorded the behaviours and classified them into four categories according to the observation form. The playing time and walking time of each level were also recorded. After completing the mazes, children were asked to fill out a paper questionnaire of 29 items including enjoyment, interdependence and usability scale. In the end, a short interview of 3 questions was conducted orally.

The results showed that both GUI and TUI have high enjoyment and interdependence, with no significant differences found. However, in terms of performance, the TUI groups took less time to complete the entire game and each level separately than the GUI groups. In the TUI condition, it is common to use verbal behaviours for collaboration, rather than the non-verbal behaviours common in the GUI condition. Finally, after comparing the frequency of using electronics and playing time, engagement and usability, TUI was found to be more appropriate for children who have no prior technology experience of the digital world and low levels of cognitive development. However, there are also some limitations in strictly ensuring valid comparison, the prototype, and the restriction of current Covid-19. In order to improve these possible issues, there are several suggestions to improve the comparison between GUI and TUI for supporting positive goal interdependence.

9 Future Work

As mentioned in the procedure section from the user study, different devices were used to display the maze screen. Based on my results of observations, the children often pointed directly at the screen to communicate with their peers during the game. Although the game screens on the iPad (GUI) and laptop (TUI) were the same sizes, there was a keyboard between the children and the screen in the TUI condition, which resulted in children not being easy to reach the screen. This potentially limited the children's ability to use their fingers to express ideas on the screen. Although some excited children still got up from their chairs to point at the screen, the obstruction of the keyboard may also have been a reason why the children were more willing to communicate verbally in the TUI condition. So, if the TUI interface also uses the iPad as the display screen, it will further ensure valid comparison.

The joysticks as the controller of the TUI interface were the only medium for the children to control the character, the KY-023 joystick module used in my study gave a high sensitivity. The value of each axis can change from 0 to 1023. Therefore, if the joystick is moved from one end to the other on the x-axis, the x-value will change from 0 to 1023, and the same will happen when moving along the y-axis. The values are approximately 512 when the joystick is held in the centre position. However, this sensitive joystick at the same time also brings a problem: the lack of precision. For example, when I lightly push the joystick to try to make the character walk slowly, it cannot do that. The value will directly jump to 0 or 1023, cannot be stable at 200 or 300. This problem had an impact to some extent in the experiment, especially for children more likely to push the joystick at once to the end, causing the character to take a few more steps than they thought. Although the children became slowly familiar with the joysticks, it would be nice to find a more stable joystick to replace it, especially for smaller children who don't have enough finger dexterity.

As a comparative study, a sufficient number of participants is very important. In my user study, there were only 20 children in total due to the pandemic, the age difference between the children was also big and 80% of the children came from the same family, perhaps these factors could impact collaboration, completion time, enjoyment, engagement, and usability. Therefore, on one hand, it is also essential to find children with a smaller age difference (7 or 8 years old). Then the understanding of the questionnaire could also be more precise, and the results will be more accurate. On the other hand, it is also important to find children who have different relationships, such as they do not know each other before, to explore whether the relationship has any effect on collaboration.

According to the feedback from the children during the interviews, some of them suggested that more levels, coins, monsters and even backgrounds could be added. This corresponds to the mean playing time of fewer than 20 minutes for both interfaces, especially for the TUI condition only around 10 minutes. Too short playing time could lead to insufficient observational data about collaboration, so it is essential to add levels of play to keep children more immersed in the game. Furthermore, because some older children can complete the five levels of the maze very easily, it is important to increase the difficulty of the maze. However, if the difficulty of the maze is to be increased, the size of the maze will have to be increased accordingly, and then a larger screen will be needed to display it.

In this study, I only recorded the observation data for all five levels together and not for each level separately. Although based on my observation the children communicated more when the mazes became more difficult. However, in order to investigate whether difficulty would have an impact on collaboration, it is also possible to have the quantitative data of each level to support my subjective observation.

A General Addenda

A.A Consent Form in German

Einverständniserklärung

1. Mir ist bewusst, dass die Erhebung, Verarbeitung und Nutzung meiner Daten auf freiwilliger Basis erfolgt. Die Erhebung kann von mir jederzeit ohne Nennung von Gründen abgebrochen werden, ohne dass mir hieraus Nachteile entstehen. Im Fall eines Abbruchs werden alle von mir aufgezeichneten Daten unwiderruflich gelöscht.
2. Ich erkläre mich damit einverstanden, dass meine Daten
    a. zur Demographie (Alter in Jahren, Geschlecht, Beziehung zum Partner, Spielerfahrung)
    b. Ergebnisse einer Umfrage zur subjektiven Bewertungen während des Labyrinthspiels (schriftliche Aufzeichnung der Antwort durch den Versuchsleiter, sowie Tonband-Aufzeichnung der Antwort des Studienteilnehmers)

    verarbeitet werden.
3. Ich wurde darauf hingewiesen, dass der von mir ausgewählte Code dazu genutzt wird, um die Daten der verschiedenen Studienteile zusammenzuführen. Mein Name wird nicht in Verbindung mit den hier erhobenen Daten und dem Studiencode gebracht.
4. Ich bin damit einverstanden, dass meine Daten durch die Ludwig-Maximilians-Universität (LMU) München zu den folgenden Zwecken erhoben, verarbeitet, genutzt und gespeichert werden:
    a. Ich erkläre mich damit einverstanden, dass die Ergebnisse und Primärdaten dieser Studie durch die Ludwig-Maximilians-Universität München als wissenschaftliche Publikation veröffentlicht werden dürfen. Dies geschieht in vollständig anonymisierter Form, d.h. ohne dass die Daten den jeweiligen TeilnehmerInnen an der Studie zugeordnet werden können. Die vollständig anonymisierten Daten dieser Studie werden als „open data" in einem sicheren, internetbasierten Repositorium namens Open Science Framework (https://osf.io/) zugänglich gemacht. Damit folgt diese Studie den Empfehlungen der Deutschen Forschungsgemeinschaft (DFG) zur Qualitätssicherung in Bezug auf Nachprüfbarkeit und Reproduzierbarkeit wissenschaftlicher Ergebnisse, sowie der optimalen Datennachnutzung.
    b. Die anonymisierten Daten werden **für einen unbefristeten Zeitraum** gespeichert.
5. Ich bin darauf hingewiesen worden, dass die im Rahmen der vorstehenden Zwecke erhobenen persönlichen Daten meiner Person unter Beachtung des Datenschutzgesetzes (DSGVO und BayDSG) verarbeitet werden.
6. Des Weiteren wurde ich darauf hingewiesen, dass ich die erteilte Einwilligungserklärung ohne Angabe von Gründen mit Wirkung für die Zukunft abändern oder gänzlich widerrufen kann. Meine Widerrufserklärung kann ich unter Angabe des Studientitels „Tangible User Interface for Supporting Goal Interdependence" und meines Studiencodes postalisch oder per E-Mail richten an

    LMU München, Lehrstuhl für Medieninformatik
    z.Hd. Zhenhan Gao
    Frauenlobstraße 7A
    80337 München
    Zhenhan.Gao@campus.lmu.de

    Außerdem habe ich nach Studienteilnahme bis Januar 2022 die Möglichkeit, die vollständige Löschung meiner Daten unter Angabe **meines Studiencodes** bei der LMU München zu erwirken, solange die Daten noch diesem Code zuordenbar sind.

Ich habe verstanden, dass meine Daten nach Ablauf dieser Frist vollständig anonymisiert werden und somit nicht mehr gelöscht werden können.

7. Mir ist bekannt, dass ich nach der Datenschutz-Grundverordnung (DSGVO) ein Recht auf die Auskunft über meine bei der Ludwig-Maximilians-Universität gespeicherten personenbezogenen Daten habe. Zu diesem Zweck wurde mir zudem ein Informationsblatt zum Datenschutz mit weiteren Informationen ausgehändigt. Wegen dieser Auskünfte und eventueller weiterer Erläuterungen wende ich mich postalisch oder per E-Mail an

   LMU München, Lehrstuhl für Medieninformatik
   z.Hd. Zhenhan Gao
   Frauenlobstraße 7A
   80337 München
   Zhenhan.Gao@campus.lmu.de

Durch meine Unterschrift versichere ich, dass ich obige Einverständniserklärung gelesen und verstanden habe und somit über meine Rechte informiert wurde. Ich versichere, dass ich der Verarbeitung meiner Daten durch die **LMU München** zustimme.

____
Ort, Datum

____
Unterschrift des Erziehungsberechtigten des/der Studienteilnehmer/in

____
Ort, Datum

____
Unterschrift des/der Studienleiters/in

A.B Consent Form in English

Consent Form

1. I am aware that the collection, processing and use of my data are voluntary. The survey can be cancelled by me at any time without mentioning reasons and without causing me any disadvantages. In the event of cancellation, all data recorded of me will be irrevocably deleted.
2. I agree that my following data are processed:
    a. demography (age in years, gender, relationship with partner, game experience)
    b. results from a questionnaire on subjective ratings during the maze game (written record of the answer by the experimenter, as well as tape-record of the answer of the study participant)
3. I have been informed that the code I have selected will only be used to merge the data from the different parts of the study. My name is neither associated with the collected data nor with the study code.
4. I agree that my data will be collected, processed, used and stored by Ludwig-Maximilians- Universität (LMU) Munich for the following purposes:
    a. I agree that the results and primary data of this study may be published by the LMU Munich as a scientific publication. The data is published completely anonymously, i.e. the collected data cannot be related to respective participants. The fully anonymized data from this study will be made available as "open data" in a secure, Internet-based repository called the Open Science Framework (https://osf.io/). Thus, this study follows the recommendations of the Deutsche Forschungsgemeinschaft (German Research Foundation) for quality assurance in terms of verifiability and reproducibility of scientific results, as well as optimal data reuse.
    b. The anonymized data is stored for **an indefinite period of time**.
5. I have been informed that my personal data collected in the context of the above purposes will be processed in compliance with the General Data Protection Regulation (GDPR and BayDSG).
6. Furthermore, I have been informed that I can amend the given consent without stating any reasons with effect for the future or revoke it completely. I can send my declaration of cancellation by stating the study title "Tangible User Interface for Supporting Goal Interdependence" and my study code by post or e-mail to

    LMU Munich, Media Informatics Group
    Attn: Zhenhan Gao
    Frauenlobstraße 7A
    80337 Munich
    Zhenhan.Gao@campus.lmu.de

    In addition, after taking part in the study until January 2022, I have the opportunity to obtain the complete deletion of my data at LMU Munich by stating **my study code**, as long as the data can still be assigned to this code.

    I have understood that my data will be completely anonymized after this deadline and thus cannot be deleted.
7. I am aware that according to the General Data Protection Regulation (GDPR) I have a right to information about my personal data stored at the LMU Munich. For this purpose, I was also given an information sheet on data protection with further information.

Because of this information and any further explanations, I can contact the experimenter by post or e-mail

LMU Munich, Media Informatics Group
Attn: Zhenhan Gao
Frauenlobstraße 7A
80337 Munich
Zhenhan.Gao@campus.lmu.de

By my signature, I assure that I have read and understood the above consent and thus was informed about my rights. I certify that I agree to the processing of my data by the LMU Munich.

____________________________ ____________________________________

Place, Date Signature of the study participant's parent/gradian

____________________________ ____________________________________

Pace, Date Signature of the study experimenter

A.C Information for the Parents for User Study in German

Probandeninformation

Es freut uns sehr, dass Sie sich bereit erklären, an der Studie „Tangible User Interface for Supporting Goal Interdependence“ teilzunehmen. Diese Studie ist Teil eines Projektes der Ludwig-Maximilians-Universität München und wird unter der Leitung von Zhenhan Gao durchgeführt.

MOTIVATION: Eine positive Interdependenz der Ziele ist ein wichtiges Element für eine effektive Kooperation. Alle Mitglieder sollten sich aufeinander verlassen können, um das Ziel zu erreichen, und müssen glauben, dass sie miteinander verbunden sind, um erfolgreich zu sein. Ziel der Studie ist es, herauszufinden, welche Art von interaktiver Benutzeroberfläche am effektivsten ist, um Kinder zu ermutigen, die gegenseitige Abhängigkeit zu unterstützen. Die Ergebnisse dieser Studie können genutzt werden, um die Art und Weise, wie Kinder heute zusammenarbeiten, zu verbessern und so die Wirksamkeit und Bedeutung der Zusammenarbeit noch weiter zu steigern.

Die Studie besteht aus zwei Teilen:

Teil 1 (ca. 30 Minuten):
Sie werden fünf Labyrinthe mit unterschiedlichen Schwierigkeitsgraden und ein Lehrniveau mit Ihrem Partner auf dem iPad oder mit externen physischen Joysticks auf dem Computer machen.

Teil 2 (ca. 15 Minuten):
Anschließend werden Sie gebeten, einen Fragebogen zur Bewertung des Labyrinths auszufüllen. Auch hier werden keine Namen gespeichert, all Ihre Daten werden einem Pseudonym zugeordnet. Am Ende gibt es ein kurzes Interview mit Ihnen über Ihre Erfahrungen mit dem Spiel.

Ihr Studiencode ist ______. Falls Sie nachträglich Ihre Einverständniserklärung widerrufen wollen, geben Sie bitte Ihren Studiencode an.

A.D Information for the Parents for User Study in English

Information for Participants

We are very pleased that you agree to participate in the “Tangible User Interface for Supporting Goal Interdependence” study. This study is part of a scientific project of LMU Munich and is being conducted under the direction of Zhenhan Gao.

MOTIVATION: Positive goal interdependence is an important element for effective collaboration. All members should rely on one another to achieve the goal and need to believe that they are linked together to succeed. The study's goal is to determine what type of interactive interface would be most effective in encouraging children to support interdependence. The findings of this study can be utilized to improve how children collaborate today, improving the efficacy and significance of collaboration even more.

The study consists of two parts:

Part1 (about 30 minutes):

You will need to complete five different difficulty mazes and a teaching level with your partner on the iPad or with external physical joysticks on the computer.

Part 2 (about 15 minutes):

Afterwards, you will be asked to fill in a questionnaire on the evaluation of the maze. Your name or personal details are not collected. In the end, there is a short interview with you about your experiences with the maze game.

Your study code is ______. If you subsequently wish to revoke your consent, please provide your study code.

A.E Questionnaire for children in German

Questionnaire_DE

- ID_Code:

- Wie alt bist du?
  ☐ 5-6 ☐ 7-8 ☐ 9-10 ☐ älter als 10

- Ich bin ein ☐ Junge ☐ Mädchen

- Wie ist Ihre Beziehung zu Ihrem Partner?
  ☐ Geschwister ☐ Mitschüler ☐ Fremde

- Wie oft benutzt du das iPad oder den Computer bei dir zu Hause oder in der Schule?
  ☐ niemals ☐ einmal im Monat ☐ einmal pro Woche
  ☐ einmal am Tag oder öfter

- Hast du schon einmal das Labyrinth gespielt?
  ☐ Ja ☐ Nein

- Ich spiele gerne Labyrinthe.

Hinweise: Wählen Sie in jeder Ansicht diejenige aus, die am besten zu Ihrer Idee passt, und kreisen Sie das Gesicht ein.

1. Ich habe dieses Spiel sehr genossen.

2. Dieses Spiel hat Spaß gemacht.

3. Ich fand, das war ein langweiliges Spiel.

4. Dieses Spiel hat meine Aufmerksamkeit überhaupt nicht gehalten.

5. Ich würde dieses Spiel als sehr interessant beschreiben.

6. Ich fand, dieses Spiel war sehr angenehm.

7. Während ich spielte, dachte ich darüber nach, wie sehr es mir gefallen hat.

8. Ich helfe meinem Partner gerne beim Spiel.

9. Ich spiele gerne Spiel zusammen mit meinem Partner.

10. Ich kann Hilfe von meinem Partner im Spiel bekommen.

11. Beim Spiel versuche ich, meine Ideen mit meinem Partner zu teilen, wenn ich glaube, dass es für ihn/sie hilfreich sein wird.

12. Ich mache es gerne besser als mein Partner beim Spiel.

13. Ich möchte der Beste im Spiel sein.

14. Ich konkurriere/vergleiche mich gerne mit meinem Partner bei Spielen, um zu sehen, wer am besten spielen kann.

15. Ich mag die Herausforderung, zu sehen, wer der Beste im Spiel ist.

16. Es stört/nervt mich, wenn ich das Spiel mit meinem Partner spielen muss.

17. Ich spiele das Spiel besser, wenn ich alleine spiele.

18. In kleinen Gruppen zu spielen ist besser als alleine zu spielen.

19. Ich spiele nicht gerne mit meinem Partner im Spiel.

20. Ich würde das Spiel gerne noch viel mehr spielen.

21. Das Spiel war schwer zu spielen.

22. Ich fand, das Spiel war einfach zu spielen.

23. Ich brauche Hilfe, um das Spiel weiter zu spielen.

24. Ich wusste, was ich als nächstes tun sollte, als ich das Spiel spielte.

25. Einige Dinge in dem Spiel machten keinen Sinn.

26. Das Spiel würde für meine Freunde leicht zu spielen.

27. Um das Spiel zu spielen, musste ich einige seltsame/komische Dinge tun.

28. Ich war stolz darauf, wie ich das Spiel gespielt habe.

29. Ich muss noch viel lernen, um das Spiel zu spielen.

A.F Questionnaire for children in English

Questionnaire_EN

- ID_Code:

- How old are you?
  ☐ 5-6 ☐ 7-8 ☐ 9-10 ☐ older than 10

- I am a ☐ boy ☐ girl

- Which is your relationship with your partner?
  ☐ sibling ☐ classmate ☐ stranger

- How often do you use the iPad or computer at your home or your school?
  ☐ never ☐ about once a month ☐ about once a week
  ☐ about once a day or more

- Have you ever done a maze before?
  ☐ Yes ☐ No

- I like doing mazes.

Instructions: Choose the one on each view that best fits your idea and circle the face.

1. I enjoyed playing this game very much.

2. This game was fun to play.

3. I thought this was a boring game.

4. This game did not hold my attention at all.

5. I would describe this game as very interesting.

6. I thought this game was quite enjoyable.

7. While I was playing this game, I was thinking about how much I enjoyed it.

8. I like to do it better than my partner in this game.

9. I like to be the best in this game.

10. I like to compete with my partner in this game to see who can play the best.

11. In this game, I try to share my ideas with my partner when I think it will help him/her.

12. I like to do it better than my partner in this game.

13. I like to be the best in this game.

14. I like to compete with my partner in this game to see who can play the best.

15. I like the challenge of seeing who is best in this game.

16. It bothers me when I have to play this game with my partner.

17. I play this game better when I play alone.

18. Playing in small groups is better than playing alone.

19. I don’t like playing with my partner in this game.

20. I would like to play this game a lot more.

21. This game was hard to play.

22. I thought this game was easy to play.

23. I would need help to play this game more.

24. I knew what to do next when I played this game.

25. Some things in this game made no sense.

26. This game would be easy for my friends to play.

27. To play this game I had to do some weird things.

28. I was proud of how I played this game.

29. There was a lot to learn to play this game.

A.G Observation form in English

Observation form

- Some possible behavior

1. **Pointing at an iPad or computer screen**
   -> Non-verbal helping

frequency	non-verbal helping
↔	
↕	

2. **Gesturing in the air with hand gestures**
   -> Non-verbal helping

frequency	non-verbal helping
↔	
↕	

3. **Take his/her partner's hand to help with the operating**
   -> Non-verbal helping

frequency	non-verbal helping
↔	
↕	

4. **Directly pushing away his/her partner's hand or body to gain control of from him/her**
   -> Non-verbal helping
   -> Displeasure (Depends on the expression and the reaction of the partner)

frequency	non-verbal helping	displeasure
↔		
↕		

- Verbal and facial expressions

  1. Talking to each other

  -> Verbal helping such as “upwards”

  -> Sharing ideas “Let's take this way to get the coin”

  -> Displeasure “You are stupid!”

frequency	verbal helping	sharing ideas	displeasure
↔			
↕			

2. Unhappy facial expressions such as frowning or pouting

frequency	Unhappy facial expressions
↔	
↕	

List of Figures

List of Tables

References

[1] A. Almjally, K. Howland, and J. Good. *Comparing TUIs and GUIs for Primary School Programming*, page 521–527. Association for Computing Machinery, New York, NY, USA, 2020.

[2] A. Antle and A. Wise. Getting down to details: Using learning theory to inform tangibles research and design for children. *Interacting with Computers*, 25:1–20, 01 2013.

[3] A. Bangor, P. Kortum, and J. Miller. Determining what individual sus scores mean: Adding an adjective rating scale. *J. Usability Studies*, 4(3):114–123, may 2009.

[4] J. Brooke. SUS: A quick and dirty usability scale. *Usability Eval. Ind.*, 189, Nov. 1995.

[5] L. K. Cheng, C. S. Der, M. S. Sidhu, and R. Omar. GUI vs. TUI: Engagement for Children with No Prior Computing Experience. *electronic Journal of Computer Science and Information Technology*, 3(1), July 2011.

[6] C. A. Collazos, L. A. Guerrero, J. A. Pino, and S. F. Ochoa. Collaborative scenarios to promote positive interdependence among group members. In J. Favela and D. Decouchant, editors, *Groupware: Design, Implementation, and Use*, pages 356–370, Berlin, Heidelberg, 2003. Springer Berlin Heidelberg.

[7] M. Fan, A. N. Antle, C. Neustaedter, and A. F. Wise. Exploring how a co-dependent tangible tool design supports collaboration in a tabletop activity. In *Proceedings of the 18th International Conference on Supporting Group Work*, GROUP '14, page 81–90, New York, NY, USA, 2014. Association for Computing Machinery.

[8] A. A. Gokhale. Collaborative Learning Enhances Critical Thinking. *Journal of Technology Education*, 7(1), Sept. 1995.

[9] D. Hecht, M. Reiner, and A. Karni. Enhancement of response times to bi- and tri-modal sensory stimuli during active movements. *Experimental brain research. Experimentelle Hirnforschung. Expérimentation cérébrale*, 185:655–65, 04 2008.

[10] M. S. Horn, E. T. Solovey, R. J. Crouser, and R. J. Jacob. Comparing the use of tangible and graphical programming languages for informal science education. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '09, page 975–984, New York, NY, USA, 2009. Association for Computing Machinery.

[11] H. Ishii. Tangible bits: Beyond pixels. In *Proceedings of the 2nd International Conference on Tangible and Embedded Interaction*, TEI '08, page xv–xxv, New York, NY, USA, 2008. Association for Computing Machinery.

[12] S. Järvelä, P. Häkkinen, M. Arvaja, and P. Leinonen. Instructional Support in CSCL. In J.-W. Strijbos, P. A. Kirschner, and R. L. Martens, editors, *What We Know About CSCL*, pages 115–139. Springer Netherlands, Dordrecht, 2004.

[13] D. Johnson, R. Johnson, and K. Smith. Active Learning: Cooperation in the College Classroom. *The Annual Report of Educational Psychology in Japan*, 47, Jan. 1998.

[14] D. W. Johnson and R. T. Johnson. An educational psychology success story: Social interdependence theory and cooperative learning. *Educational Researcher*, 38(5):365–379, 2009.

[15] D. W. Johnson and A. A. Norem-Hebeisen. A measure of cooperative, competitive, and individualistic attitudes. *The Journal of Social Psychology*, 109(2):253–261, 1979.

[16] K. Kreijns, P. Kirschner, and W. Jochems. Identifying the pitfalls for social interaction in computer-supported collaborative learning environments: A review of the research. *Computers in Human Behavior*, 19:335–353, 05 2003.

[17] M. Laal. Positive interdependence in collaborative learning. *Procedia - Social and Behavioral Sciences*, 93:1433–1437, 10 2013.

[18] M. Laal and S. M. Ghodsi. Benefits of collaborative learning. *Procedia - Social and Behavioral Sciences*, 31:486–490, 2012. World Conference on Learning, Teaching & Administration - 2011.

[19] M. Laal and M. Laal. Collaborative learning: what is it? *Procedia - Social and Behavioral Sciences*, 31:491–495, 2012. World Conference on Learning, Teaching and Administration - 2011.

[20] P. Marshall. Do tangible interfaces enhance learning? In *Proceedings of the 1st International Conference on Tangible and Embedded Interaction*, TEI '07, page 163–170, New York, NY, USA, 2007. Association for Computing Machinery.

[21] P. Marshall, R. Fleck, A. Harris, J. Rick, E. Hornecker, Y. Rogers, N. Yuill, and N. S. Dalton. Fighting for control: Children's embodied interactions when using physical and digital representations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '09, page 2149–2152, New York, NY, USA, 2009. Association for Computing Machinery.

[22] H. Michailidis, E. Michailidi, S. Tavoultzidou, and G. Fragulis. Teaching young learners a foreign language via tangible and graphical user interfaces. *SHS Web of Conferences*, 102:01014, 01 2021.

[23] C. O'Malley and D. Fraser. Literature review in learning with tangible technologies. *NESTA Futurelab Rep.*, 12:1–48, 01 2004.

[24] C. Putnam, M. Puthenmadom, M. A. Cuerdo, W. Wang, and N. Paul. Adaptation of the system usability scale for user testing with children. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*, CHI EA '20, page 1–7, New York, NY, USA, 2020. Association for Computing Machinery.

[25] J. C. Read and S. MacFarlane. Using the fun toolkit and other survey methods to gather opinions in child computer interaction. In *Proceedings of the 2006 Conference on Interaction Design and Children*, IDC '06, page 81–88, New York, NY, USA, 2006. Association for Computing Machinery.

[26] R. Ryan. Intrinsic motivation inventory (imi), 2006.

[27] T. Sapounidis and S. Demetriadis. Tangible versus graphical user interfaces for robot programming: Exploring cross-age children's preferences. *Personal Ubiquitous Comput.*, 17(8):1775–1786, dec 2013.

[28] B. Schneider, P. Jermann, G. Zufferey, and P. Dillenbourg. Benefits of a tangible interface for collaborative learning and interaction. *IEEE Transactions on Learning Technologies*, 4(3):222–232, 2011.

[29] O. Shaer and E. Hornecker. Tangible user interfaces: Past, present, and future directions. *Found. Trends Hum.-Comput. Interact.*, 3(1–2):1–137, jan 2010.

[30] E. Sharlin, B. Watson, Y. Kitamura, F. Kishino, and Y. Itoh. On tangible user interfaces, humans and spatiality. *Personal and Ubiquitous Computing*, 8:338–346, 09 2004.

[31] B. Smith and J. MacGregor. What is collaborative learning? *Wash Cent News*, 7, 01 1993.

[32] K. Smith. Craft of teaching cooperative learning: An active learning strategy. *Proceedings - Frontiers in Education Conference, FIE*, pages 188–193, 1989. 1989 Frontiers in Education Conference ; Conference date: 15-10-1989 Through 17-10-1989.

[33] T. Speelpenning, A. N. Antle, T. Doering, and E. van den Hoven. Exploring how tangible tools enable collaboration in a multi-touch tabletop game. In P. Campos, N. Graham, J. Jorge, N. Nunes, P. Palanque, and M. Winckler, editors, *Human-Computer Interaction – INTERACT 2011*, pages 605–621, Berlin, Heidelberg, 2011. Springer Berlin Heidelberg.

[34] M. Van Mechelen, B. Zaman, A. Laenen, and V. V. Abeele. Challenging group dynamics in participatory design with children: Lessons from social interdependence theory. In *Proceedings of the 14th International Conference on Interaction Design and Children*, IDC '15, page 219–228, New York, NY, USA, 2015. Association for Computing Machinery.

[35] A. Wise, A. Antle, J. Warren, A. May, M. Fan, and A. Macaranas. What kind of world do you want to live in? positive interdependence and collaborative processes in the tangible tabletop land-use planning game youtopia. In O. Lindwall, P. Hakkinen, T. Koschmann, P. Tchounikine, and S. Ludvigsen, editors, *Exploring the Material Conditions of Learning*, Computer-Supported Collaborative Learning Conference, CSCL, pages 236–243. International Society of the Learning Sciences (ISLS), 2015. Funding Information: We gratefully acknowledge the support of NSERC, SSHRC, and GRAND NCE in making this project possible. Publisher Copyright: © ISLS.; 11th International Conference on Computer Supported Collaborative Learning: Exploring the Material Conditions of Learning, CSCL 2015 ; Conference date: 07-06-2015 Through 11-06-2015.

[36] A. F. Wise, M. Saghafian, and P. Padmanabhan. Towards more precise design guidance: Specifying and testing the functions of assigned student roles in online discussions. *Educational Technology Research and Development*, 60(1):55–82, Feb. 2012.

[37] D. M. Woods and K.-C. Chen. Evaluation Techniques For Cooperative Learning. *International Journal of Management & Information Systems (IJMIS)*, 14(1), Jan. 2011.

[38] L. Xie, A. N. Antle, and N. Motamedi. Are tangibles more fun? comparing children's enjoyment and engagement using physical, graphical and tangible user interfaces. In *Proceedings of the 2nd International Conference on Tangible and Embedded Interaction*, TEI '08, page 191–198, New York, NY, USA, 2008. Association for Computing Machinery.

[39] D. Xu. Tangible user interface for children - an overview. In *in Proceedings of the SIXTH Conference in the Department of Computing*, pages 579–584, 2005.

[40] O. Zuckerman and A. Gal-Oz. To tui or not to tui: Evaluating performance and preference in tangible vs. graphical user interfaces. *International Journal of Human-Computer Studies*, Volume 71:Pages 803–820, 04 2013.