

Title: Together Through the Medieval Hellscape - How Tangible User Interfaces Promote Collaboration in Video Games

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Abstract:

Project group: MED6 Group 7

Participants:

Jacob Vigsø

Marcel Kress

Frederik L. K. Nørregaard

Blake Rodgers

Søren Lasskogen

Mathias Jaqué

Supervisor:

Ivan Adriyanov Nikolov

Co-supervisor:

Daniel Overholt

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Tangible user interfaces (TUIs) have shown to promote collaboration in learning contexts, but their role in cooperative game design remains underexplored. This project explored the impact TUIs have on collaboration in video games. An analysis was conducted on teamwork and collaboration, where key factors on how to promote collaboration through TUIs and video games respectively, were identified. Based on its findings, a set of custom TUIs - the O.R.B.S - were designed and built to promote collaboration through forced interdependence, alongside a cooperative videogame, SpellBound, which served as the testbed for the TUIs. The study sought to investigate how the custom TUIs promote collaboration, compared to conventional gamepads. A between subjects comparative study was conducted, where one group played SpellBound using the O.R.B.S. (group A), against another group who played SpellBound using conventional gamepads (group B). The method included one pre-test questionnaire (CCSS), two post-test questionnaires (GEQ, SPGQ), observational analysis, and a behavioral game (Prisoner's Dilemma), all aiming to measure collaboration and teamwork behaviors. The tests indicated that, generally, group A exhibited greater collaborative tendencies. The TUIs seemed to promote explicit coordination, closeness, similarity and bonding, but the tests lacked statistical power to confirm the proposed hypothesis.

Together Through the Medieval Hellscape: How Tangible User Interfaces Promote Collaboration in Video Games



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MEDIALOGY BACHELOR THESIS
GROUP 7

Frederik L. K. Nørregaard

Marcel Kress

Mathias Jaqué

Blake Jordan Rodgers

Søren Pugerup Lasskogen

Jacob Vigsø

Together Through the Medieval Hellscape - How Tangible User Interfaces Promote Collaboration in Video Games

Frederik L. K. Nørregaard
Aalborg University
Study no.: 20233920
pu35ss@aauniversity.dk

Blake Jordan Rodgers
Aalborg University
Study no.: 20234564
brodger23@aauniversity.dk

Marcel Kress
Aalborg University
Study no.: 20233908
mkress23@aauniversity.dk

Søren Pugerup Lasskogen
Aalborg University
Study no.: 20234281
slassk23@aauniversity.dk

Mathias Jaqué
Aalborg University
Study no.: 20233906
mjaque23@aauniversity.dk

Jacob Vigsø
Aalborg University
Study no.: 20234313
jvigso23@aauniversity.dk

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1 Introduction

For decades, the psychology of teamwork has been studied to determine the behaviors that emerge when individuals pursue private and common goals, laying the foundation for theories of efficiency and effectiveness in organizational teamwork [1]. Much of the surrounding research on how to deliberately foster teamwork behaviors, especially through tangible user interfaces, exists within educational contexts. Few studies examine how a tangible user interface, paired with a cooperative game, can promote teamwork through a gaming experience.

Cooperative video games have grown in popularity over the past two decades and research suggests they have an innate ability to facilitate collaboration[2], [3], [4], [5], [6], [7]. A tangible user interface has also been shown to facilitate collaboration, by making players' actions mutually visible it encourages verbal communication and interdependence [8], [9], [10], [11]. Yet the combination of cooperative games and tangible interfaces has received little direct research attention. This motivated our initial problem statement:

“How can a cooperative game and its physical interface promote teamwork?”

To investigate this, we propose the O.R.B.S (Orchestrated Relationship Building Spheres), a set of custom tangible controllers that distributes the necessary inputs between the two players through physical constraints. The O.R.B.S were developed specifically and in parallel with SpellBound, a cooperative game whose mechanics demand simultaneous and interdependent input from two players.

To evaluate the system, we conduct a between subjects comparison where one group plays SpellBound using the O.R.B.S, while another plays the same game using standard Xbox gamepads. We hypothesize that participants using the O.R.B.S exhibit a difference in their level of collaboration, compared to those using gamepads. This is measured through behavioral observations, the Cooperative/Competitive Strategy Scale (CCSS), modified Group Environment (GEQ) and modified Social Presence in Gaming (SPGQ) questionnaires, and a practical behavioral game, Prisoner's Dilemma. Our findings indicate that group A generally exhibited greater teamwork tendencies. The O.R.B.S appears to promote certain teamwork behaviors, closeness, similarity, and bonding within the team based upon the group's task. However, some findings lack strong statistical power to definitively confirm the hypothesis.

The remainder of this report is structured as follows. Sections 2 and 3 review the literature on collaboration, teamwork, and tangible interfaces. Section 4 investigates related projects and section 5 presents the final problem statement. Section 6 describes the design and implementation of the O.R.B.S and SpellBound. Section 7 presents and explains the evaluation method and findings and sections 8-10 contain discussion, conclusion, and future work.

Github link: https://github.com/Marcelkress/P6_Bachelor_WomboCombo.git

2 Collaboration and Teamwork

Collaboration can be defined as the prioritization of goals and a willingness to help partners achieve their private goals as well as common goals [12]. It is connected to coordination and cooperation; coordination concerning itself with parties agreeing on goals and cooperation focusing on carrying out said goals [12]. This project is focused on and will evaluate collaboration by this definition.

To understand how coordination and cooperation relate to one another, the following section establishes what teamwork entails. Teamwork has been defined by Salas et al. as “[...] *a set of interrelated thoughts, actions, and feelings of each team member that are needed to function as a team and that combine to facilitate coordinated, adaptive performance and task objectives resulting in value-added outcomes*” [13, p. 562]. This aligns with the project, as the experience demands shared awareness, communication, and mutual adjustment. Salas et al. goes on to establish the means of accomplishing successful coordination, cooperation and collaboration in teams with these five core components: team leadership, mutual performance monitoring, backup behavior, adaptability, and team orientation [13].

It is important to note that team leadership, while it may naturally emerge between players, is not something the experience was designed to deliberately elicit and therefore it falls outside the scope of this project. The project set out to draw on the remaining four components; **mutual performance monitoring** for having participants caring for each other’s work as well as their own; **backup behaviors** as the ability to anticipate a teammate’s needs and provide assistance through verbal feedback or by assuming and completing their task; **adaptability** for adjusting a plan to compensate for any deviations; and **team orientation** for its attitudinal foundation, the input and prioritization of individual and common goals, that facilitate the three other components. These components have been considered throughout the design process to ensure the facilitation of collaboration between participants.

2.1 Collaboration and Teamwork in games

The innate ability to facilitate and promote collaboration, suggested by related research [4], [5], [6], [7], naturally arises in cooperative games, as they often include interdependent mechanics, eliciting competencies such as communication, coordination, and cohesion [6], [7].

Interdependence describes how the outcomes of individuals are affected by their own and others’ actions. Johnson and Johnson mention two types of interdependence: positive (cooperation) and negative (competition) [14, p. 366]. This project focused on positive interdependence where the success of a person is possible only by the success of another.

Through a systematic review, Marlow et al. suggests how certain game attributes are linked to specific teamwork competencies: Collaboration, communication, cooperation, and cognition [4], [6]. The game attributes implemented for this project include: *Action language*, *Environment*, *Human interaction*, and *Immersion*.

Action language describes the ways in which players can interact with the system e.g. pressing buttons and moving the mouse. Action language also influences task interdependence. Task interdependence refers to “*the extent to which team members believe that they need information, materials, and support from other members in their teams in order to carry out their tasks*” [14], [15]. **Environment** refers to the location in which the game takes place, and that game spaces can be designed in such a way to encourage players to work together within their physical spaces. **Human interaction** refers to the interactions that take place between players outside of the game world. **Immersion**, referring to the perceptual and affective relationship between player and game, enables risk taking to further embed cohesion between participants [6].

Farah et al. further define a list of features that would categorize a video game as cooperative [16, p. 71, Table 1]. Such features include: **shared obstacles**, which is a challenge that only utilizes one action for clearance, **common risks**, which involves game dynamics that encourages players to survive together, and **limited life**, referring to limited resources amongst the players, such as limited health or food.

Combining the efforts of Marlow et al. [6], Greitemeyer et al. [4], and Farah et al. [16], we can leverage cooperative features and game attributes to promote collaboration between players through gameplay. Designing a cooperative gaming experience is crucial to the purpose of this project, as it provides the testbed of our research.

3 Tangible interfaces to support collaboration

Tangible user interfaces (TUIs) are interfaces that computationally augment physical objects by coupling them to digital data [17]. The physical object often functions as both an input and output device, providing a parallel feedback loop to users through physical or digital means. For example, haptic feedback, informing a user that a certain physical manipulation is complete, or visual/auditory feedback that informs the user of the computational interpretation of their action [17].

A divide in human-computer interaction exists between direct and indirect manipulation [9], [18]. TUIs occupy a space somewhere in the middle of this spectrum. They are direct in that users physically manipulate real objects, but the computational coupling of those objects to digital data [17] means the interaction is not purely unmediated. This matters in a collaborative context, as TUIs are situated in a shared physical space, where the more direct manipulation allows the player's actions to be visible to others. Where an indirect controller like a gamepad isolates each player behind an abstracted input interface, TUIs can make it an embodied activity, a condition under which verbal communication and coordination have been shown to increase [11]. Schneider et al. [9] reinforce this point, finding that groups using a TUI outperform those using multi-touch in problem-solving tasks.

TUIs have been shown to be a useful tool in promoting collaboration [8], [9], [10], [11]. Li [11] highlights three relevant factors; it fosters positive interdependence, brings object ownership, and the preference in users manipulating physical objects [19]. This therefore justifies TUIs as the platform for our research.

3.1 Design principles in collaborative TUIs

Several perspectives have informed how TUIs can be purposefully designed to promote collaboration between users.

Li [11] proposes three mechanisms to design positive interdependent interactions: the interaction inputs must come from both users; when solving tasks, each user must contribute to group work; only when both interaction inputs are correct are users able to proceed to the next task [11]. These mechanisms provided clear criteria for the TUI design and ensured collaboration was embedded in the final product of this project.

Truesdell et al. [20] propose three design themes for collaborative controllers: **Safety**, referring to the players having to feel socially safe when entering the play environment; **Social spaces**, addressing the way controllers can support the game-world and engage the players with their game roles; and **inter-reliance**, describing how the players' roles should be reliant on one another by controller attributes and game mechanics. The core of interreliance refers to design choices that lead to shared responsibility between players of the game's outcome. This overlaps with the definition of task interdependence presented in section 2.1 *Collaboration and Teamwork in games*, and to avoid confusion of the term interdependence, the usage of interreliance will also refer to task interdependence.

Hornecker and Burr [21] introduce the concept of embodied facilitation: physical design principles such as system size, placement, and the number of available tools, which can have a significant impact on group dynamics. Creating and designing for this can create interfaces that intentionally limit individual agency, fostering coordination, and mutual helping required for reaching cooperation [21]. Li [11] and Park et al. [22] corroborate this, finding that physical constraints inherently lead to more verbal communication.

Through this project, we designed a custom controller in accordance with these ideas, which could help promote a collaborative environment, potentially more so than traditional gamepads, which are designed to support generalized interactions across a multitude of games. Designing an alternative controller can provide the designers' ways to augment or complement the game mechanics [20, p. 2]. In relation to our project, we aimed to augment the aspects of interdependence and interreliance, seeking to further promote collaboration and teamwork amongst users.

4 Related projects

This section refers to previous research and how it combined the knowledge collected by similar studies. The TUIs described in the following section have been developed for research purposes and offer either design principles, frameworks, or data regarding tangible interfaces and collaborative games, and how they evoke collaboration.

4.1 Tangible User Interfaces by Yanhong Li

This section highlights the work of Yanhong Li [11]. The projects leverage physical objects to create interdependence between users with the goal of collaborative learning. Li investigates how physical constraints and shared control can foster a sense of shared understanding between users.

SpellBoard (see Figure 1) is a spelling game where each participant is constrained to different colored letters. Each word requires letters of both colors and therefore creates interdependence between users by limiting their resources. A key finding from this project was that interactive constraints can be designed to specifically allow participants to coordinate their collaborative actions.



Figure 1: The SpellBoard project by Li
(image courtesy of Yanhong Li)

CollabMaze (see Figure 2) is a simple maze game where the players need to escape a 2D maze using a custom controller. The players shared control over the game character. One player controls horizontal movement and the other vertical movement. They found that interdependent tangible user interfaces had high enjoyment and interdependence, and that children were more engaged in the tasks.



Figure 2: Two children using CollabMaze
(image courtesy of Yanhong Li)

MemorINO (see Figure 3) is a tangible device where each user owns a piece that both fit together in different ways. An accompanying application indicates how the pieces should go together for different tasks. The interdependence is established by the user’s ownership of the different pieces. A key finding from this project was that interactive constraints together with tangible technologies could enforce interdependence.



Figure 3: Two children interacting with memorINO

(image courtesy of Yanhong Li)

What these three projects have in common is that the interdependence is created on a tangible level. The affordances of controllers between users differ, which can then be supported by the software. These ideas have helped shape the design process of our TUI.

4.2 Haber Dasher

Haber Dasher [23] is a game that utilizes a giant hat as a controller (see Figure 4). Two players balance it on their heads and tilt it to navigate an in-game character through coordination of their movement.

The game was used in a research paper by Truesdell et al. themselves, to study embodied activity that happens through physical space interactions and constraints [24]. The paper used the Creative Sense Making Framework [25], adapted to be goal oriented instead of traditionally being open ended. They used this framework to observe how the players chose to negotiate goals etc. through various techniques.



Figure 4: Two people playing with the Haber Dasher controller

(image courtesy of Erin J. K. Truesdell)

Truesdell et al. demonstrated that highly interdependent, alternative controllers force distinct patterns of collaboration, such as prompting players to enter states of “mutual exploration” and “coupled play” to understand the interface. Similar techniques were used in this project to ensure that one player cannot dominate the game, in form of physical constraints, making it impossible to succeed in the game without active, embodied collaboration.

4.3 Tangible Moyangsung by Park et al.

Park et al. developed a collaborative virtual heritage environment game, utilizing tangible interfaces to promote social cooperation [22].

The game is based on the real-life castle Moyang-sung, and the goal is to repair its destroyed walls. The setup consisted of a control panel, a screen, and the tangible interfaces. The users navigated the virtual world with the control panel, and once they found the damaged walls, the surface would have a projected pattern, which the players had to fill in with physical Tetris-like blocks. To win the game, they had to repair all walls within 10 minutes, and if they managed to do so, they would be rewarded with a cutscene in the game, otherwise the castle would be completely destroyed.

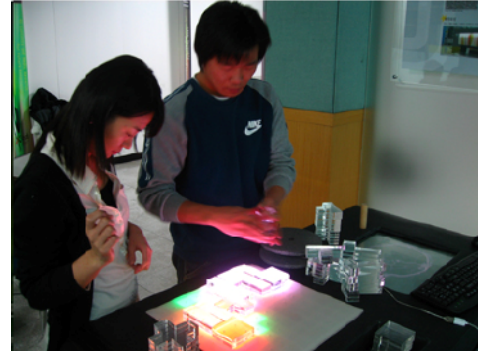


Figure 5: Persons laying the tangible bricks to repair the walls of the Moyang-sung, (image courtesy of Park)

In the study they conducted, they tested 3 conditions; individual playing, group-together playing, and group with role-division. They found that working together significantly improved completion time of the game. However, they found no significant difference between the group-together and group with role-division. But, they did find that the group with role-division group talked more during their gameplay.

Encouraging communication through role-division proved helpful to our game, as it elicits more teamwork behaviors (see Section 2 *Collaboration and Teamwork*).

4.4 Interdependent controllers in regards to social aspects

While little research aims to evaluate alternative controllers and their effect on teamwork, a large amount of research has been done regarding alternative controllers focused on social play, social connectedness, and social closeness. Such projects help lay the foundation for the design of collaborative controllers. Projects include ‘Hotaru’ [26], which incorporates interdependent wearable technology for play, or ‘In the Same Boat’ [27], which leverages the synchronization of both players’ input. ‘Ole De La Vida’ [28], a game involving a three person poncho and a set of maracas, also falls into this category, researching how co-located play experiences can lead to temporary play communities.

Social spaces are also presented by Truesdell as a prerequisite for effective collaboration with alternative collaborative controllers (see section 3.1 *Design principles in collaborative TUIs*), highlighting the importance of this work.

4.5 alt.ctrl.GDC

alt.ctrl.GDC [29] is a community space within the Game Developers Conference (GDC) [30], with a focus on state of the art alternative game controllers. The conference showcases controllers such as Haber Dasher (see section 4.2 *Haber Dasher*), and emphasizes innovation and creativity within controller and game development. It highlights the importance of continued development within the game controller space. alt.ctrl.GDC has served this project as a great source of inspiration, and has helped the research and design process.

4.6 Summary

Across the presented state of the art projects, examples of forced interdependence have been highlighted, showcasing how interdependence can be achieved at the user interface and tangible level, such as a giant hat that two users have to wear simultaneously. They also highlight how software might support interdependence, as in Li’s example, where users have to control the individual directions of a character in a game. The presented projects helped mold the design and functionality of the product of this project, and the accompanying game.

5 Final problem statement

Through analysis of teamwork, collaboration, and how it pertains to TUIs within video games, the following problem statement emerged:

Does a tangible user interface for a game designed to enforce positive interdependence promote collaboration to a higher degree than traditional input systems?

6 Design and Implementation

The following sections describe the design process for the Orchestrated Relationship Building Spheres (O.R.B.S.) and the game SpellBound, developed to accompany them. Prototypes of both will be described in terms of design and technical implementation.

6.1 Game Design Insights

Various games have been examined to directly inform the design decisions of this project in order to create a game that encourages collaboration.

Time Crisis 2 (Figure 6, top left), is a cooperative light-gun shooter arcade game, developed and published in 1997 by Namco [31]. Players cannot move freely and must defeat enemies to move through levels, where the automatic character movement serves as a resting period for the players. SpellBound utilized similar mechanics by moving players through the levels automatically, leaving them to focus entirely on the cooperative gameplay mechanics.

Typing of the Dead (1999, Figure 6, bottom left), is a horror game developed by WOW entertainment and published by Sega [32]. The core gameplay mechanic is typing-based combat, where players write arbitrary words and phrases to kill incoming enemies. The words function as enemy health bars where the player attacks by typing words.

Ztype (Figure 6, right), is another game with similar mechanics [33]. The distinction between them is that in *Typing of the Dead*, players can choose which enemy to attack at any time, where *Ztype* locks the player to a target once typing is initiated. SpellBound takes inspiration from both systems, where enemy health is represented by an arbitrary sequence of symbols, and uses *Ztype*'s method of enemy prioritization.

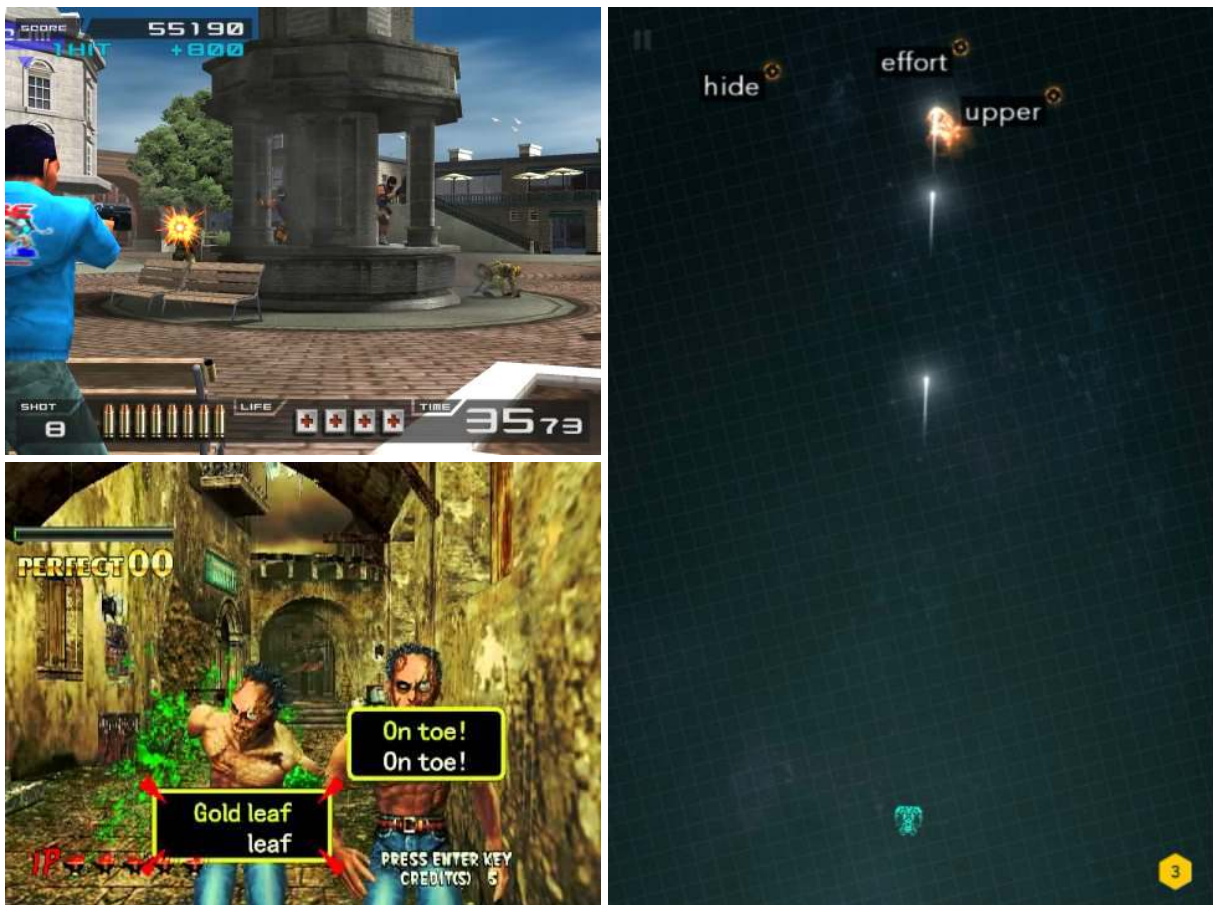


Figure 6: Top left: *Time Crisis 2*, Bottom left: *Typing of the Dead*, Right: *Ztype*

6.1.1 Collaborative mechanics in games

Creating positive interdependence by restricting individual player capabilities is a common design strategy to encourage cooperation as it forces the players to rely on one another to progress. As seen in the game *It Takes Two* [34] (see Figure 7), players can not complete a level without combining their respective abilities and helping each other.



Figure 7: *It Takes Two* platforming

Overcooked 2 [35], an abstract cooking simulator game, does not force interdependence by allowing players to switch tasks throughout the game to adapt to the needs of each level (see Figure 8). The core collaborative focus of *Overcooked 2* is effective and clear communication. It promotes this not only through the environment and small spaces with clear objectives, but also by designing the game with a hub-space where players choose levels. This allows the players to pause between levels and create a plan through team orientation. Once the plan is in play, mutual performance monitoring naturally takes place, allowing players to make use of backup behaviors as well as adaptability to provide any necessary feedback or adjustments.



Figure 8: *Overcooked 2*

This highlights the importance of the design process when designing for a collaborative game. *Spell-Bound* enforces positive interdependence by requiring simultaneous inputs from the players as well as constraining their choices of input. Furthermore, the game is seamlessly divided into sections, with small breaks in between. This allows the players to use this time for team orientation, enabling mutual performance monitoring, backup behaviors and adaptability.

6.2 Design Requirements for SpellBound

As the O.R.B.S. have been designed around SpellBound, the game's requirements are outlined first, followed by the requirements of the controller.

6.2.1 Functional Requirements

The game must:

- Be a cooperative multiplayer game.
- Enforce interdependence through gameplay mechanics.
- Encourage backup behaviors.
- Last a minimum of 15 minutes.
- Be immersive.
- Encourage cohesion.
- Encourage communication.
- Encourage collaboration.

6.2.2 Non-Functional Requirements

The game must:

- Feature a combo mechanic requiring input from two players.
- Not be completable by a single player.
- Have combos that only a single player can perform.
- Provide all relevant information to the players.
- Include optional healing.
- Be able to have multiple enemies on screen at a time.
- Have melee enemies.
- Have ranged enemies.
- Have deflectable projectiles.
- Provide downtime between enemy encounters.
- Use game assets with high quality textures.
- Incorporate diegetic sound design.

6.3 Design Requirements for the O.R.B.S.

6.3.1 Functional Requirements

The controllers must:

- Force interdependence.
- Be designed around the game's mechanics.
- Adhere to the game's visual design.
- Have reliable and consistent inputs.
- Be able to register rotation and push.
- Provide visual feedback.
- Provide haptic feedback.
- Enable role division.

6.3.2 Non-Functional Requirements

The controllers must:

- Be able to perform a combo the other can not.
- Be operated using two hands.
- Mimic the game's combo system setup, such that it visually aligns with what's on screen.
- Be built using materials and components that can withstand at least 15 minutes continuous use.
- Light up when registering push inputs. Green on valid input, and red on invalid input.
- Vibrate when the user performs an input.
- Display the same symbols as the combos in the game.

6.4 Game design

With the previous concepts in mind, we designed the cooperative game SpellBound, focusing on interdependent mechanics. This section will describe the final iteration of the mechanics, whereas the sections following this will describe the iterative process of developing them.

The formal elements of the game include two players who share one point of view and one health pool. The objective is for the players to kill enemies by casting spells and reach the final boss. To cast spells, players must perform combos by matching the top and bottom symbols of the O.R.B.S. to the symbols that appear above each enemy. A combo is defined as a sequence of combo steps, where each combo step is a combination of a top and bottom symbol. The players share the three symbols on the bottom half of the controllers (moon, star and sun), but only share one symbol on the top half (star).

Each player's controller also has an additional symbol unique to them – sun for one player and moon for the other.

These mechanics can be defined into the following game rules:

- A combo step is successfully executed when both the top and bottom symbols match, and the input action is triggered.
- Only a single combo (enemy / player health) can receive input at a time.
- Projectiles can receive input at all times.
- Combos for enemies are randomly generated, but can never start with the same combo step as another existing enemy.
- Both players have to trigger combo steps simultaneously if the top symbol is shared (star symbol).
- A healing combo is always available and can be started between enemy combos.
- Making several correct combo steps in a row will instantly kill the targeted enemy with a stronger spell.

Many of the game's mechanics are designed to directly foster collaboration and communication. For instance, as only a single enemy can receive input at a time, it encourages the players to communicate among themselves as to which enemy to target. Similarly, starting the healing combo locks the players out of starting and targeting enemies until finished. Additionally, having both offensive and defensive spells offer different ways of collaboration as they share a health pool. The mechanic that needs simultaneous inputs also adds more instances where communication is encouraged.

Furthermore, if they achieve the strong spell we assume they have communicated successfully since there have been few to no mis-inputs and are thereby rewarding them for their successful communication.

6.4.1 Iterative process - Paper prototype and development of game mechanics

The paper prototype served as a way to test the mechanics and possible ways to interact with the game. Through testing of the prototype the game rules were determined and specified.

Figure 9 shows an example of what a combo looked like for the paper prototype. The symbols on the top and bottom correspond to what the player should select on their controller. When a player triggers an action on a combo step, it is cleared and when all steps are cleared, the enemy dies and a new target can be chosen.

The controllers were represented by coffee cups with symbols drawn onto them which the players had to match by rotating the cups relative to each other (see Figure 10).

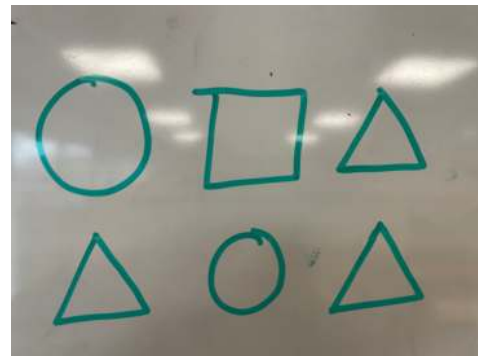


Figure 9: Enemy Combo Example

When they wished to register a combo step, they spoke their chosen symbols aloud, and pressed the input button next to them. The enemies were represented by pieces of paper with the same symbols, and were moved by hand.

The prototype showed that these basic mechanics were successful in encouraging cooperation. From the test, we also found that enemies being able to shoot projectiles was an interesting mechanic to promote discussion between players as to which target to choose.



Figure 10: Paper prototype testing

It was also noted that for the digital prototype, there should be a health pool where the players also had the opportunity to heal themselves to make it through the game.

6.4.2 Iterative process - Digital prototype

Before the digital development of the game, a technical design document was written. It contains information on how game systems should be implemented, pseudo code for scripts and standards for how symbols are treated in code. See appendix 11.14 *Technical design document*.

The first digital prototype was focused on getting the enemy combo systems working. The enemy system consists of two scripts: *EnemyManager* is responsible for spawning enemies at various locations in the world and assigning a unique combo to each one. *Enemy* handles the enemy's own UI, displays the assigned combo for the players to execute and removes individual combo steps as they are completed.

To support local multiplayer, Unity's Input System was integrated, with an input action asset containing action maps for both players. Player inputs are managed by an input manager that tracks each player's currently selected symbols. These inputs are broadcasted project-wide through events, allowing other systems, such as the enemies, to subscribe and respond accordingly. See section 6.5 *Final Design and Implementation* for an overview of game systems. At this stage, the prototype supported both gamepad and keyboard inputs. A simple UI was also implemented for each player to display their currently active symbols, primarily serving as a debugging aid. Whether this UI would be retained for user testing remained undecided at this stage.

Following this initial implementation, the enemy system was extended to incorporate a dedicated *EncounterManager* script. This script tracks the player's progression through the game and uses it to trigger the corresponding *EnemyManager.cs* for each encounter, instructing it to begin spawning enemies at their designated locations as the player reaches them.



Figure 11: Digital prototype

6.5 Final Design and Implementation

The final iteration of the game improved the system in multiple ways. One of the most notable changes was the complete overhaul of the game's visuals (see Figure 12). The semi-realistic environment largely uses an asset pack [36] from the Unity Asset Store, as well as two different models for melee and ranged enemies. Additionally, visual effects including a fireball and lightning strike were added when performing combo steps. The strong spell was implemented and triggered when the players perform multiple correct combo steps in a row.



Figure 12: Visuals in final iteration

6.5.1 Technical improvements and changes

The communication layer between Unity and the O.R.B.S. was built to ensure the game's compatibility with both gamepads and the O.R.B.S.

The data from the custom controllers is sent to the host computer via USB serial, where the script `ControllerInputCrossPlatform` was written in order to read the serial data. Figure 13 shows the code structure within Unity and illustrates the connections between scripts.

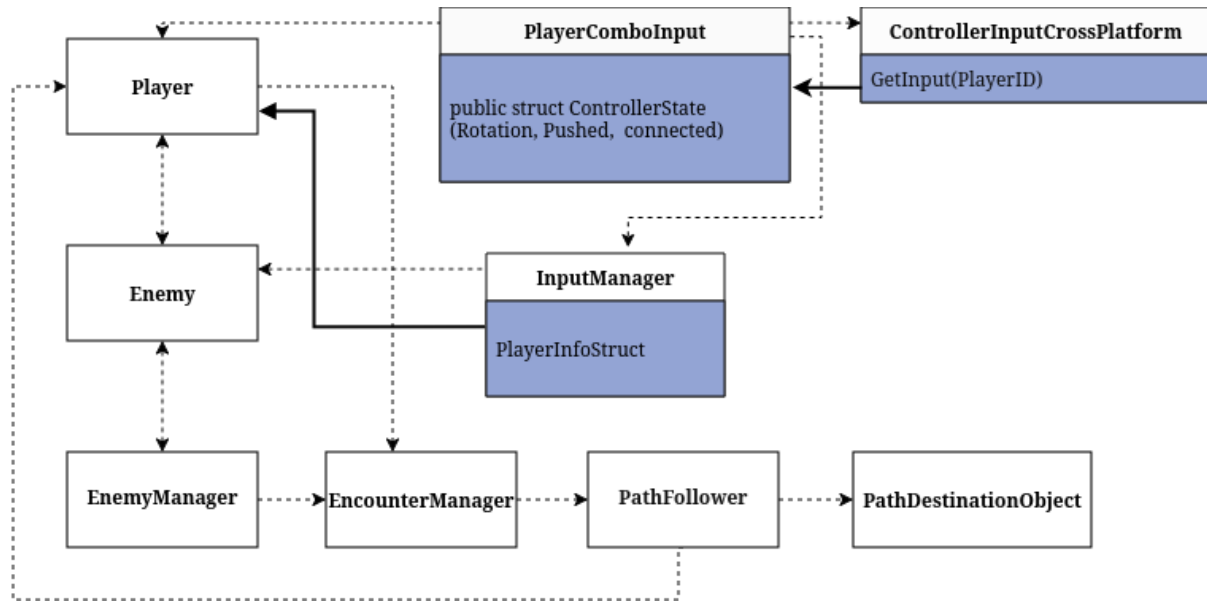


Figure 13: Core Code Structure

In Figure 13, boxes with two compartments show the script name alongside a key field or method exposed by that script. Dashed arrows indicate a dependency or subscription to events. Solid arrows indicate a direct method call or data flow where arrowheads show the general flow of logic.

Each script is responsible for the following:

- **PlayerComboInput:** Convert controller rotation values to symbol values (moon, star, sun).
- **InputManager:** Contains updated player combo info, spawns players upon receiving input.
- **Player:** Manages health, healing spell and updates player UI (Healthbar & symbols).
- **Enemy:** Navigate to and attack player, tracks own combo, updates own UI.
- **EnemyManager:** Spawns enemies in an encounter, generates random combos for each enemy.
- **EncounterManager:** Tells EnemyManagers when to spawn, tells player game object to move when an encounter is complete, provides following the encounter details: enemy count, min/max combo length, spawn delay and more.
- **PathFollower:** Generates a path for moving player game object based on waypoints, moves player camera along waypoints.
- **PathDestinationObject:** Waypoint along path.

6.6 Tangible User Interface (TUI) design

The final TUI was built upon the paper prototype's design, affording the same possibilities, refining its appearance, conforming to the aesthetic of the game, establishing communication with Unity and creating feedback for users.

It consists of two 3D-printed halves that lock together. Each half has the symbols from the game embossed in the design. Users can rotate the halves to align the symbols and press them together to send the input.

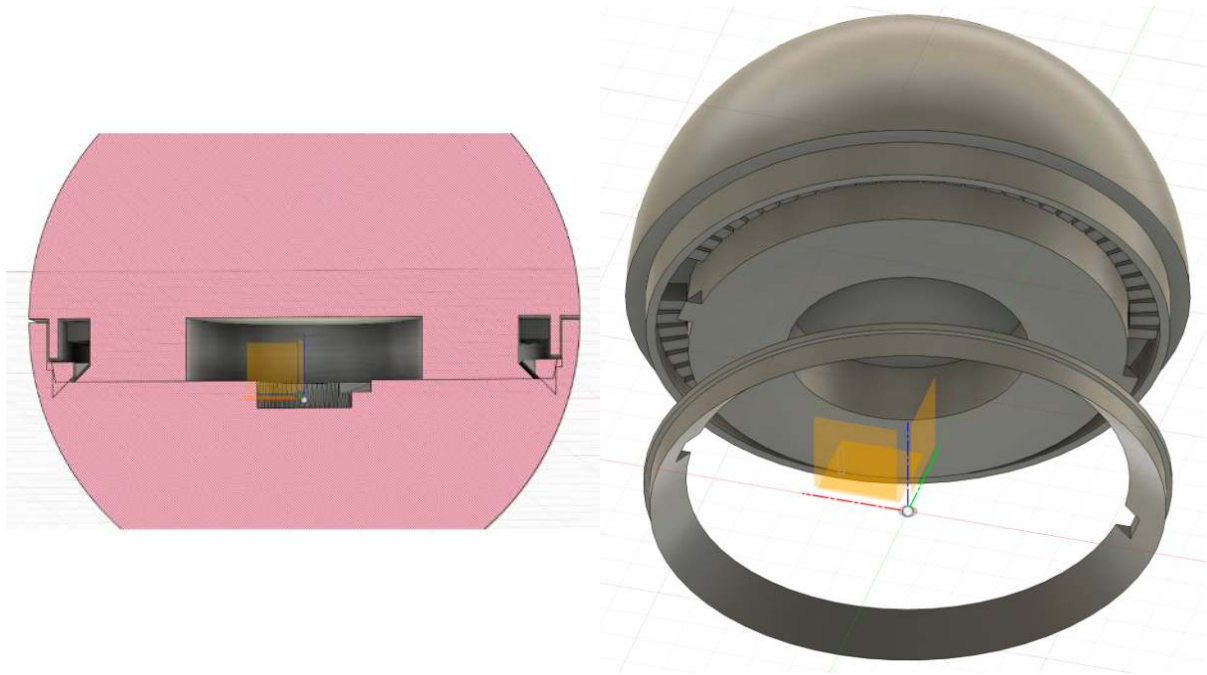


Figure 14: Left: *Cross section of interlocked halves*, Right: *Bottom view of halves*

The lower half houses the electronic components. As depicted in Figure 14, gaps along the rail join and lock the halves in place. The encoder keeps track of the rotation and push values which are sent to the ESP providing haptic and visual feedback. When symbols are aligned the LEDs light up green, if not the LEDs light up red. To confirm and send a combination of symbols, the top and bottom halves are pressed together triggering vibration and lighting the entire LED strip around the sphere either green or red to indicate a valid or invalid input.

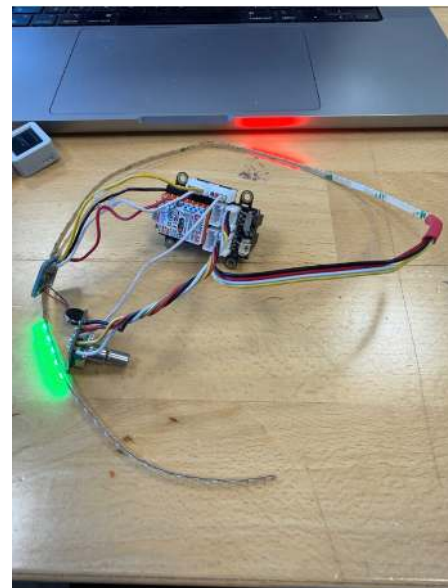
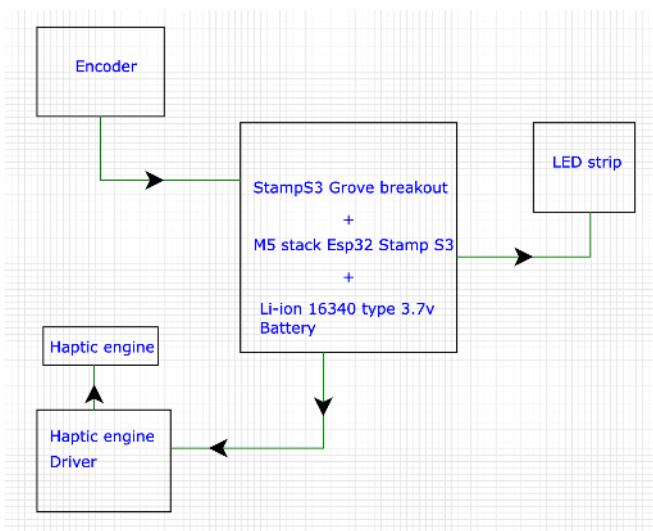


Figure 15: Left: *Flow Diagram electrical of the components in the Controller*, Right: *The final electronics components*

An M5 Stamp S3 ESP32 drives the electronic components in a breakout board. Figure 15 shows the relationships between the inputs and outputs of the following components:

- Rotary encoder for rotational and press state data read by the ESP.
- Haptic engine and LED strip are controlled by the rotary encoder via the ESP.

The complete electronics can be seen in Figure 15. Each component can be found in 11.15 *Components table*.

Design challenges and solutions

While creating the O.R.B.S., challenges arose as its increasingly complex components required 5 volts instead of 3.7 and spatial confinements became insufficient. Table 1 serves to outline notable changes made during development.

Initial Components	Final Components	Reason
Sparkfun ESP32 Thingplus S2	M5 stack StampS3 ESP32	Spatial optimization + Increased voltage requirement
2x 3.7V Li-Po batterycell in series + voltage regulator to reduce to 5V	3.7V li-ion type 16340 + M5 stack Breakoutboard with built in boost converter	Spatial optimization + increased voltage requirement
Potentiometer	Rotational encoder	Adding button and 360 rotational freedom

Table 1: Design challenges and changes to components

6.7 Iterative process - Rotation data read

The default value from the rotational encoder returns an integer that increases infinitely. However, to ensure consistent data for the game logic, this needs to be clamped. A function was written that calculates the modulo 30 of the rotation value, such that when the encoder makes a full rotation, the values reset to 0. This allows us to define exact ranges that correlate to the matched symbols on the TUI. Through manual reading, a set of ranges were then defined that correspond to the matching symbols in game.

See code snippet below:

```
#define COUNTS_PER_REV 30

/*...*/

// — Read encoder —————

//Gets the total count from power-on
long rawCount = encoder.getCount();

//Uses modulo to find position within the current revolution:
int positionInRev = rawCount % COUNTS_PER_REV;
//Fixes potentially negative values and makes them positive
if (positionInRev < 0) positionInRev += COUNTS_PER_REV;

//The int that stores our final rotation value.
int stepValue = positionInRev;

//Only sends data when the count changes
if (rawCount != lastRawCount) {
    Serial.printf("rawCount: %ld | stepValue: %d\n", rawCount, stepValue);
    lastRawCount = rawCount;
    lastValue = stepValue;
    sendPacket(stepValue, 0);
}
```

6.7.1 Iterative process - ESP-NOW and sending data

Communication between the O.R.B.S. and Unity was afforded through another ESP acting as the controller receiver. The controllers transmit the input data over the ESP-NOW protocol. This allows for low latency and instant pairing using the receiver's MAC address [37]

The ESP-NOW protocol however, only functions between ESP devices, creating the need for USB-serial communication from the receiver to the computer running SpellBound. The connections can be seen in Figure 16.

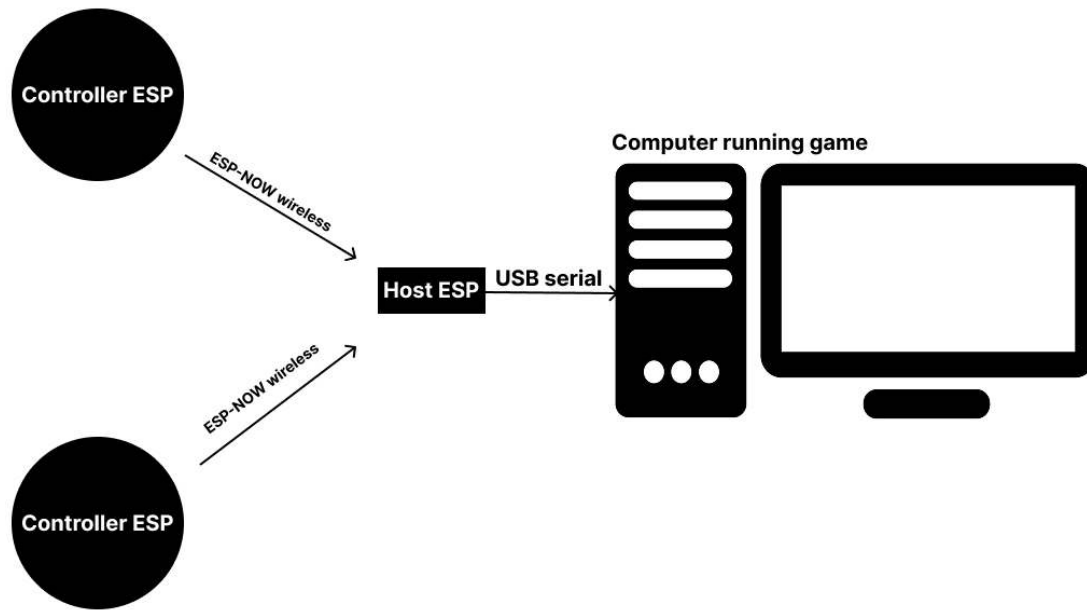


Figure 16: Connections between ESP and computer

6.7.2 Final design of the O.R.B.S.

The final iteration of the O.R.B.S. was printed and assembled with the electronics, finalizing its design process. Two controllers were created: white with black symbols and black with white symbols, see Figure 17.



Figure 17: Final physical design

6.8 Usability test

The usability test aimed to evaluate both the O.R.B.S. and the accompanying game.

In terms of the O.R.B.S., the test aimed to evaluate the participants' performance, and whether their desired actions were accurately received by the device and translated in the game.

The usability test also aimed to evaluate the game's difficulty to ensure the participants' ability to reach the ending, while still feeling challenged. In addition, testing sought to identify any bugs and balancing issues.

6.8.1 Method

The test participants were tasked with completing the game, followed by a SUS questionnaire. The SUS questionnaire is a widely used tool to evaluate the overall perceived usability of a system, represented by a single number [38]. The gameplay was video recorded on a phone behind the test participants, capturing both the gameplay and the participants' usage of the controllers. The footage allowed for identification of bugs within the game, alongside the gameplay leading up to the incidents. It also allowed for evaluating the flow of the gameplay. In terms of the O.R.B.S., footage contributed the assessment of the O.R.B.S. accuracy in capturing the actions intended by the participants. The usability test was conducted for two iterations.

6.8.2 Sampling

The test participants were all recruited through convenience sampling [39, p. 61], finding readily available test participants within our vicinity. Convenience sampling allows for a quick gathering of participants, and therefore quick testing which accelerates project development.

The first round of test participants consisted of 1 woman and 7 men, all university students in the age range of 20-31. The second round consisted of 4 women and 2 men, all university students in the age range of 20-26.

6.8.3 First iteration results

The calculation of the SUS scores are based on the methods presented by Sauro and Lewis [40, p. 26-28], see Table 2. According to the curved grading scale, also presented by Sauro and Lewis [38], the first round of testing resulted in A- to A+ grading. All participants completed the demo without much issue, and took little to no damage, which resulted in most not even attempting the healing

mechanic. The completion time for the first round was between 3-5 min, which was much shorter than anticipated. This short completion time might also explain the high scores, as the participants had very little time to use the O.R.B.S., which may have shielded them from experiencing its shortcomings. Through observations, it was found that the very first enemy encounter was overwhelming for the participants.

Based on these results, the game's length was extended to better match the requirement of a 15 minute experience (see Section 6.3.1 *Functional Requirements*), and the enemy encounters in the game were further balanced. Attempting to achieve a ramping difficulty, the enemy encounters would gradually go from single enemies, to multiple, and ending in a boss battle.

A tutorial was also created with the goal of introducing the players to the game's mechanics. As they would be learning the controls together, it provides an additional opportunity for communication.

6.8.4 Second iteration results

The second round of usability tests resulted in a SUS grading between C to A+, showcasing a larger dispersion of scores, but still at a minimum an average rating. As the second round of usability tests also had less participants, this also contributed to the larger confidence interval. While the SUS score dropped, other metrics improved, see Table 3. Completion time increased to 14:52 on average, exactly 10 min longer than before, meeting the requirement of a 15 min experience. While the death count did not change significantly, the average healing count increased by almost triple, showcasing a need for strategic choices in the game. Completion rate remained at 100%, which at a glance is not undesirable, but based on observations, the final boss seemed too easy for the participants to defeat.

SUS results	Round 1	Round 2	Metrics	Round 1	Round 2
Mean	87.19	76.25	Completion rate	100%	100%
Standard deviation	7.96	10.72	Avg. completion time	4:52	14:52
Standard error	2.81	4.38	Avg. healing count	1.00	2.66
Margin of error	6.50	10.73	Avg. death count	0.50	0.33
Confidence interval (95%)	80.69 - 93.68	65.20 - 86.98	Table 3: Metrics of usability test		

Table 2: Results from the SUS questionnaires

6.8.5 Changes before final test

While the desired completion time, and a better healing count was achieved, the final boss seemed too easy to defeat. The difficulty of the final boss was therefore increased slightly by making their projectiles stronger; instead of requiring a single combo step to deflect a projectile, they would occasionally need two.

7 Evaluation

The study within this project sought to investigate whether a tangible user interface (TUI) designed to enforce positive interdependence in a cooperative game, would cause a difference in promoting collaboration than a traditional gamepad. To evaluate this, a comparative experimental approach was implemented where two conditions were set against each other. Both groups played the game *SpellBound*, which was developed for this project and is described in detail in Section 6 *Design and Implementation*. Group A played the game with the O.R.B.S, and group B played the game with Xbox gamepads.

The game was built around positive interdependent mechanics which the TUI was designed to reinforce, by constraining each player's available inputs, requiring both to contribute distinct actions in order to progress. TUIs foster positive interdependence, make actions visible and increase verbal communication in a collaborative context (see Section 3 *Tangible interfaces to support collaboration*). This led to the following hypotheses:

H_1 : *Participants playing SpellBound with the custom TUIs will exhibit a difference in their level of collaboration from participants using traditional gamepads.*

H_0 : *Participants playing SpellBound with the custom TUIs will not exhibit a difference in their level of collaboration from participants using traditional gamepads.*

The hypotheses rest on two premises:

The first premise is that tangible user interfaces, combined with positive interdependence promote collaboration. The analysis supports this, as Li [11], Schneider et al. [9] and Hornecker and Burr [21] all find that TUIs and physical constraints foster communication and coordination between users. Johnson and Johnson [14] also corroborate that positive interdependence leads to cooperation, as success relies on the success of others. Both of these principles are designed into the game and the TUI. However, the majority of this research has been done in educational contexts rather than games. Whether these findings transfer to a cooperative gaming context is, in part, what this study aims to investigate.

The second premise is that the game and the two conditions are capable of showing differences in collaboration. This assumes that the game requires enough collaborative efforts to produce observable behaviors and that the TUI distinguishes itself from conventional gamepads through its inherently interdependent mechanics. Previous paper prototype testing did provide initial evidence that such mechanics were capable of fostering collaboration.

7.1 Method

7.1.1 Sampling

The participants for the test were recruited through convenience sampling. This was mainly due to time limitations, as the recruitment and testing only spanned a week. As convenience sampling was used, it is important to not over generalize the data as the sampling method may produce biases [39].

A total of 22 participants were recruited for the test and were split into two groups; 12 into group A and 10 into group B. The participants were between the ages of 22 to 29 years old, 15 being male, 5 female and 2 non-binary. The participants had a varying range of weekly hours spent playing video games. 11 participants played video games 4-10 hours/week, 5 of them played 10+ hours/week, 3 of them played 1-3 hours/week, and the last 3 played 0 hours/week.

7.1.2 Test Instruments & Procedure

Various testing instruments were used during the procedure of the test to collect multiple data points which enabled the study to triangulate the data. Only quantitative data was collected and procured

for the results of the study. All collected data has been anonymized and assigned an ID according to their group.

The first questionnaire administered to participants was the Cooperative/Competitive Strategy Scale (CCSS) questionnaire [41], which served as a pre-test to establish a baseline measure of participants' innate attitudes to collaborate and compete between groups. These attitudes are measured on a scale of 1-7. Tang's 1999 study [41] presents an average of 3.7 for cooperation and 3.8 for competitiveness with a sample size of $n=309$. Higher scores indicate higher tendency to act according to the respective behaviors.

Once the pre-test was completed, the participants were introduced to the game which they played in pairs for approximately 15 minutes. Participants were allowed to go past 15 minutes of playtime if they were close to completing the game. Participants were paired on the basis that they either had very few or no social interactions with each other. The play-session was recorded and used for observational analysis. Due to limitations of the observational material, mutual performance monitoring was deemed unfeasible and is therefore not included in the results.

Upon completion of the play-sessions, participants were administered two questionnaires in sequence, a modified Group Environment Questionnaire (GEQ) [42], [43], [44] and a modified Social Presence in Gaming Questionnaire (SPGQ) [45].

The modified GEQ (see Appendix 11.11 *Modified Group Environment Questionnaire*) was used to assess how participants perceived the experience and their teammate. It was modified because only two of the four sub-scales were deemed relevant for the study. The two sub-scales used were Interpersonal Attraction to the Group - ATG-T (task) to assess the individual's feelings about their personal investment to the group's task and Group Integration - GI-T (task) to assess the individuals feelings about closeness and bonding within the team based upon the group's task [44]. Each sub scale scores between a range of 1-9, with 1 being the lowest and 9 being the highest.

The modified SPGQ (see Appendix 11.12 *Modified Social Presence Questionnaire*) was used to assess how participants perceived the level of interdependence on a scale from 0 to 4 within the experience, with 4 being the highest and 1 being the lowest. Only one of the three sub-scales, behavioral engagement, was used, as the others were not deemed relevant for the study.

Cronbach's alpha was calculated for the modified GEQ and SPGQ sub-scales. Every test achieved a Cronbach's alpha of $\alpha > 0.700$, as seen in table Table 4. Cronbach's alpha is a tool for measuring internal consistency [46].

Cronbach's α (95%)	Estimate	Std. Error	Lower	Upper
(GEQ ATG-T)	0,703	0,084	0,539	0,867
(GEQ GI-T)	0,757	0,090	0,581	0,933
(SPGQ)	0,873	0,025	0,825	0,921

Table 4: Cronbach's alpha for the GEQ and SPGQ sub-scales

1-3 hours after the test was finished, the participants were asked to engage in the second part of the test. This required them to participate in a behavioral game called Prisoner's Dilemma. The Prisoner's Dilemma game, or a variant of it, has been used to evaluate teamwork tendencies in previous studies [4], [47]. The delay between the original test and the Prisoner's Dilemma was primarily due to logistical issues. As each pair was tested one at a time, all tests had to be completed before it was possible to make new pairs within the group.

The procedure followed in order to conduct the Prisoner's Dilemma was presented by Badatala et al. [47]. The game involves two players, who are matched with an anonymous partner. The game lasts

between 10-20 rounds, and each round, the players choose either option X or Y. If both participants choose option X, they each gain 5 points. If they both choose option Y, they each lose 5 points. If one chooses X, and the other chooses Y, the person choosing Y gains 10 points, and the person choosing X loses 10 points. The participants do not know when the game ends, to avoid optimization strategies [48]. For the evaluation of the study, all participants were matched with a new anonymous partner within group, who were not their original partner during the playthrough of SpellBound. This was done to avoid the confounding variable of a prior relationship between participants. To ensure consistency in the data, the game would end after 13 rounds, and the participants would only be informed once round 13 was played through.

Figure 18 visualizes the entirety of the final test.

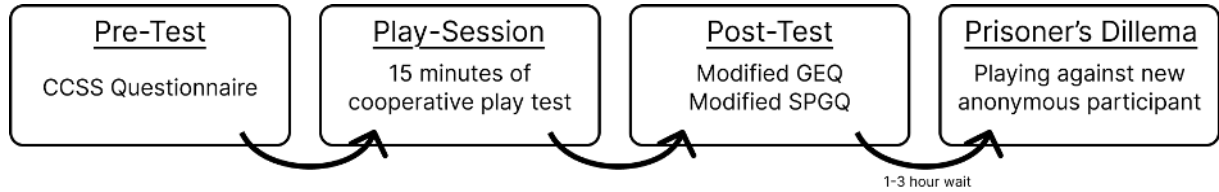


Figure 18: Flow diagram of the final test procedure

7.2 Research questions

To assist the evaluation of the hypotheses, the following research questions were investigated, which all relate directly to the test instruments:

RQ₁: How do the CCSS scores differ within pairs, and do they display any meaningful impact on the subsequent data?

RQ₂: How do the GEQ scores differ between groups?

RQ₃: How do the SPGQ scores differ between groups?

RQ₄: How do the behavioral marker counts differ between groups?

RQ₅: How do the scores of the Prisoner's Dilemma game differ between groups?

7.3 Data analysis

7.3.1 Observational Data

For each test session, the behavioral markers of the participants were coded and counted. Behavioral markers are a way of evaluating team metrics through analyzing the behavior of teammates when playing cooperative video games [16].

A behavioral marker was noted when more than one teammate was verbally or behaviorally engaged in teamwork. The markers for this study were chosen from the paper “*Evaluating Team Metrics in Cooperative Video Games*” by Farah et al. [16] based on the relevancy for the study. The markers are individually described in Table 5.

Marker	Description
Backup behavior (BB)	Teammates responding to help request, player supporting partner without request
Implicit coordination (IC)	Coordination or act that benefits team without explicit communication
Explicit coordination (EC)	Teammate reporting status or engaging in timing of movements through explicit communication
Planning (P)	Teammates planning a sequence of actions to solve a problem
Adaptability (A)	Team adapting to a new strategy after certain events
Failures (F)	Failing due to lack of skill or communication
Task cohesion (TC)	Teammate expressing enthusiasm towards team goal

Table 5: Behavioral markers

All recordings were coded by two persons within the project group, who subsequently compared their results, only counting the markers they both noted, to ensure intercoder reliability [39, p. 110]. First, markers were individually placed with timestamps in the videos. The timestamps between the individual coders were then compared, and each timestamp of the same type, that matched within a maximum of 5 seconds, was counted as valid.

7.3.2 Questionnaire Data

The questionnaires employed for this evaluation are not standardised, excluding the CCSS, and are therefore not comparable to any global scale. The focus of this evaluation is therefore comparing data between the groups, to note any possible effect of the O.R.B.S.

The CCSS scores are originally an independent score, yet the GEQ and SPGQ are dependent, as the participants have been playing with another person. To accommodate this, the CCSS scores have been combined to a single score, expressing the difference in cooperativeness and competitiveness within pairs, which in this report will be presented as agreeability. This allows for correlational analysis between the CCSS scores, questionnaire data and observational data.

For the modified GEQ questions 1, 2, 3, 4, 5, 6, 9, 11 were all reversed in the collected data and combined into a single score. The data from the GEQ and SPGQ were then averaged within groups and compared between groups.

7.3.3 Prisoner's Dilemma

The Prisoner's Dilemma data analysis also follows the process by Badatala et al. [47], which combines the scores of the participants within pairs. This total sum expresses the collaboration of the pair. Higher scores, indicate a higher level of collaboration between the participants.

7.3.4 Statistical analysis

To further understand the data, Mann-Whitney U tests were conducted to analyze the effect size between groups A and B and their respective questionnaire (Q) scores, Prisoner's Dilemma (PD) scores and behavioral marker (BM) counts. Spearman's Correlation analysis was conducted for questionnaire scores and behavioral marker counts within group. PD scores are excluded from correlation analysis as participants were paired differently in that stage of testing. These methods were chosen due to their ability to handle smaller sample sizes.

7.4 Results

This section presents the findings of the evaluation. It was found across tests, that the group playing with the O.R.B.S (group A), generally exhibited more teamwork behaviors, and greater teamwork tendencies after the experience, compared to the group playing with the gamepads (group B).

The Spearman's correlational analyses provided insight into what might have caused these differences between groups, such as the O.R.B.S' innate ability to promote certain behaviors. The results and heatmap of the correlational analysis can be found in its entirety in appendix 11.8 *Group A Q Score Correlation* and 11.9 *Group B Q Score Correlation*.

The following section presents the data that led to these findings.

7.4.1 CCSS Scores

The cooperative and competitive attitudes observed in pairs between groups showed an observable, albeit very small, difference in effect size, see Table 6.

	U	p	Effect size	95% CI	
				Lower	Upper
CCSS COOP	60.50	1.000	-0.008	-0.465	0.452
CCSS COMP	52.50	0.643	0.125	-0.354	0.552

Table 6: CCSS scores between groups

Group A and group B exhibited small to negligible differences in cooperation scores ($r = -0.008$) and competitiveness scores ($r = 0.125$). This is reflected in the mean values, see Table 7. On the other hand, group A and B show a similar level of agreeability in terms of cooperation although slightly lower for group A ($r = -0.300$). However, they diverge noticeably in group B when it comes to competitiveness ($r = 1.000$).

	CCSS COOP		CCSS COMP		Gaming Hrs/Week	
	A	B	A	B	A	B
Mean (arithmetic)	3,292	3,360	3,992	4,140	6,917	7,500
Std. Deviation	0,502	0,306	0,496	0,717	4,542	5,893
Minimum	2,000	2,900	3,000	3,300	0,000	0,000
Maximum	3,900	3,800	4,700	5,400	15,00	15,00

Table 7: Pre-test results

With regards to RQ_1 , it is relevant to look at the Spearman's correlation analysis of the CCSS, and subsequent data collections, see Figure 19 and Figure 20.

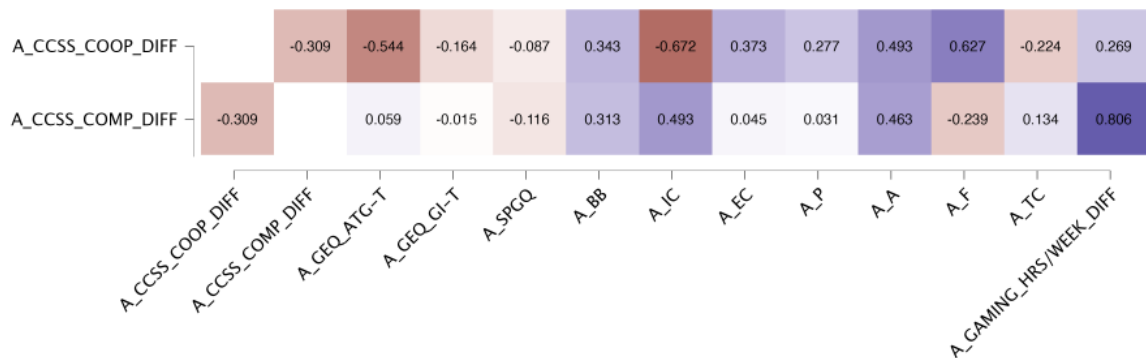


Figure 19: CCSS score differences between pairs for group A, correlated with the subsequent data

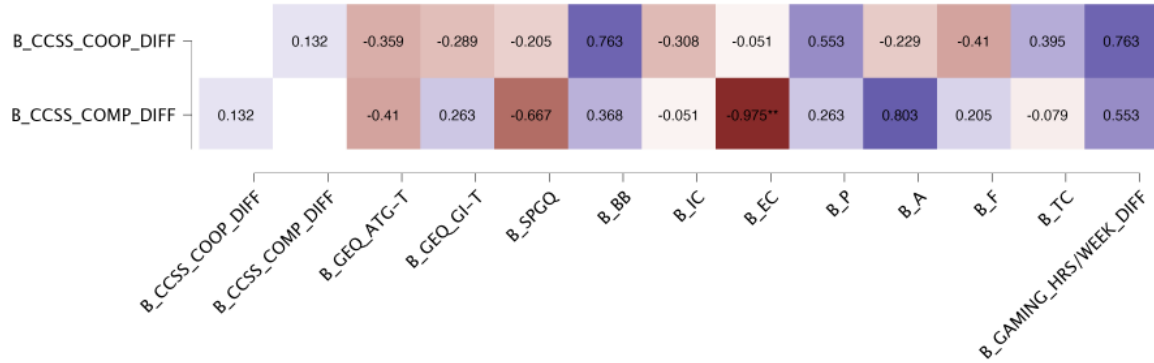


Figure 20: CCSS score differences between pairs for group B, correlated with the subsequent data

For group A, there is generally a weak to no correlation between the CCSS_COMP_DIFF and the subsequent data. There are 2 outliers, IC and A, as these show medium level of correlation. However, looking at group B, there seems to be multiple medium to large correlations between the CCSS_COMP_DIFF and the data, such as EC, SPGQ and A. This suggests that the O.R.B.S helps mitigate the competitive differences that might interfere with teamwork behavior.

The CCSS_COOP_DIFF correlational data shows a range of weak to moderate correlation for the subsequent data, for both group A and B. A larger set of outliers are observed, such as the correlations for GEQ_ATG-T, IC and F for group A, and BB, P and GAMING_HOURS/WEEK_DIFF for group B. This suggests that the difference in attitude toward cooperation within pairs, could have affected the subsequent results, to some degree.

7.4.2 GEQ and SPGQ Scores

The post-test GEQ scores differ the most within the GI-T sub scale, see Table 8. Group A shows a higher score compared to group B, which is again shown by the effect size and the mean value. However, ATG-T scores do not differ much, see Table 9. There is also little to no difference, especially within mean values, between the groups' SPGQ scores. For agreeability, the tests showed strong differences for SPGQ and GEQ GI-T scores between groups. In these instances, pairs in group A showed more agreeability than group B.

	GEQ ATG-T		GEQ GI-T		SPGQ	
	A	B	A	B	A	B
Mean (arithmetic)	7.733	7.760	8.397	7.150	2.950	2.720
Std. Deviation	0.692	1.264	0.373	1.245	0.550	0.466
Minimum	6.400	6.100	7.880	5.250	2.200	2.200
Maximum	8.300	8.800	9.000	8.500	3.600	3.400

Table 8: GEQ scores, and SPGQ scores

Regarding RQ_2 , the results show a moderate to weak effect size for the GEQ ATG-T favoring group B ($r = 0.267$), indicating that they expressed a higher tendency to be more individually invested in the common goals during the combined tasks. In contrast, the GEQ GI-T showed a moderate to strong effect size favoring group A ($r = -0.667$), meaning they reported a greater sense of closeness and bonding with their partner through the combined tasks.

	U	p	Effect size	95% CI	
				Lower	Upper
GEQ ATG-T	11.00	0.522	0.267	-0.416	0.757
GEQ GI-T	25.00	0.079	-0.667	-0.909	-0.089
SPGQ	19.50	0.462	-0.300	-0.772	0.385

Table 9: GEQ and SPGQ scores between groups

Answering RQ_3 , the results show a moderate to weak effect size for the SPGQ favoring group A ($r = -0.300$). This could lead to further support of the hypothesis by indicating that group A felt more interdependent with their partner during the experience than group B did.

See appendix 11.11 *Modified Group Environment Questionnaire* and 11.12 *Modified Social Presence Questionnaire* for the complete results.

7.4.3 Behavioral Markers Counts

In the observational data, group A exhibited a higher degree of behavior linked to teamwork theory in 2 out of 7 categories and effect sizes indicate a moderate to strong difference in values for Explicit Coordination (EC) ($r = -1.000$) and Task Cohesion (TC) ($r = -1.000$). The remaining categories show Group B displaying more BM counts. For Implicit Coordination (IC) ($r = 0.800$) analysis shows a strong difference between groups, while Backup Behavior (BB) ($r = 0.400$), Planning (P) ($r = 0.367$), Failure (F) ($r = 0.433$) and Adaptability (A) ($r = 0.067$) only show a weak to moderate difference. See appendix 11.6 *Descriptive Statistics: Between Group Behavioral Marker Count* and 11.7 *Mann-Whitney U: Between Group Behavioural Marker Count* for the complete results.

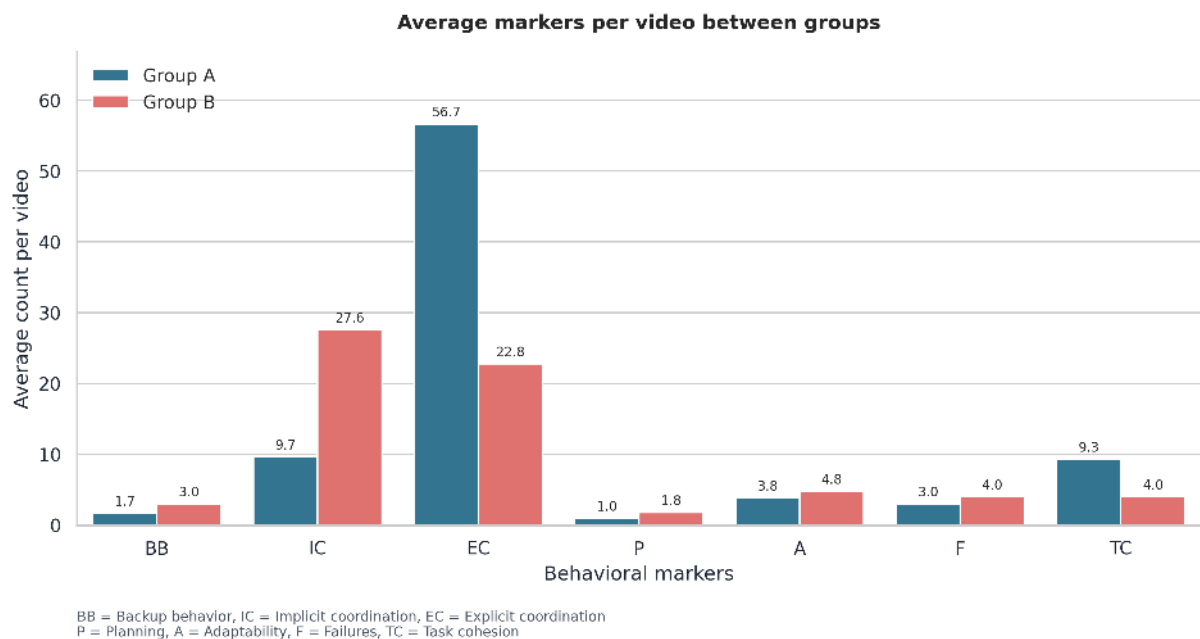


Figure 21: Figure showing average markers per video between groups

Through investigation of the behavioral markers in terms of RQ_4 , some notable differences appeared in implicit coordination (IC) and explicit coordination (EC). This indicates that using the O.R.B.S led to more explicit coordination, whereas the gamepads elicited more implicit coordination. This is also reflected through the Spearman's correlational analysis of IC and EC. As group B had no correlation between IC and EC, group A had a negative correlation, implying that more EC behavior results in lower IC for group A. This shows the tendency that the O.R.B.S requires more EC, compared to

gamepads, that required both types of coordination. In addition, the means of the IC and EC group B have a similar count of IC and EC, where group A has a significantly larger EC count than IC count.

A higher difference in gaming hrs/week within pairs seemed to have little to no correlation with the implicit (Spearman's $\rho = 0.091$) and explicit coordination (Spearman's $\rho = 0.273$) behaviors in group A. However, group B's gaming hrs/week difference within pairs displayed a moderate, negative correlation to both of these behaviors (Spearman's $\rho = \text{IC } -0.667 / \text{EC } -0.41$). This suggests that the behavior that arises when playing with the O.R.B.S, are independent of previous gaming experiences, where it affects the behaviors of group B.

The O.R.B.S seem to encourage explicit coordination behavior among players, which is supported when observing the correlations between EC and IC in group A (Spearman's $\rho = -0.818$) and group B (Spearman's $\rho = -0.1$). Group A's strong correlation seems to suggest that the O.R.B.S encourage explicit coordination. Mean scores for these behaviors also reflect this point as group A was observed almost exclusively performing EC.

The correlation between the GEQ scores and behavioral markers, also show some notable relationships. F and GEQ ATG-T (Spearman's $\rho = 0.8$) and GI-T (Spearman's $\rho = 0.564$) indicate failures are necessary for the team's attraction to the group in group B. Group A, however, shows a negative correlation between F and GEQ GI-T (Spearman's $\rho = -0.561$), proposing that the more failures led to a decline in group integration, which could indicate that the O.R.B.S does not handle failure in the same way a traditional gamepad does.

7.4.4 Prisoners' Dilemma Scores

Regarding RQ_5 , the PD scores between groups display a mean difference of 22.5 points in favor of Group A, see Table 10. The effect size of the Mann-Whitney U test, however, states this as a small difference at -0.200 , see Table 11. This effect size supports our hypothesis by showing a difference between groups. The data came out in favor of group A, suggesting a higher degree of collaboration on average compared to group B. At the study's current statistical power it is not possible to reject the H_0 .

Group	A	B
Median	50,00	20,00
Mean (arithmetic)	52,50	30,00
Std. Deviation	66,02	63,25
Minimum	-20	-40
Maximum	130	130

Table 10: Prisoner's Dilemma team scores

	U	p	Effect size	95% CI	
				Lower	Upper
PD Scores	12.00	0.711	-0.200	-0.763	0.535

Table 11: Prisoner's Dilemma scores between groups

7.5 Key Findings

The CCSS test displayed negligible differences between groups, indicating little to no pre-test bias. For group B, competitive differences within pairs, showed stronger correlation with subsequent results, suggesting that the O.R.B.S may mitigate competitive attitudes.

The GEQ results showed how group A reported stronger group bonding (GI-T: effect size $r = -0.667$), but no meaningful differences were observed in personal task investment (ATG-T). The SPGQ results showed that group A perceived greater interdependence compared to group B (SPGQ: $r = -0.300$).

Through the behavioral marker counts, it was found that group A exhibited more explicit coordination (EC) than group B who exhibited more implicit coordination. However, group B exhibited similar levels of explicit and implicit coordination within group. This suggests that the O.R.B.S encouraged or required explicit verbal coordination.

The Prisoner's Dilemma test results showed a mean score between groups of 52.50 points in group A and 30 points in group B, coming to a 22.5-point difference. With an effect size of -0.200 , the results at the current statistical power are insufficient for rejecting the null hypothesis.

Across tests, group A generally exhibited greater collaboration. The O.R.B.S appears to promote explicit coordination, closeness, similarity, and bonding within the team based upon the group's task (GI-T). However, some findings lack strong statistical power to definitively confirm the hypothesis.

8 Discussion

8.1 Validity and reliability

To assess the reliability of the testing tools, Cronbach's alpha was calculated for the GEQ and SPGQ sub-scales. For all sub-scales the Cronbach's alpha came out to be greater than 0.7, indicating an acceptable level of internal consistency. In addition, intercoder reliability was ensured in the data gathering process of the observational data. However, in terms of the data itself, the ability to reproduce the results is difficult. A majority of the data had a wide confidence interval, meaning the reliability of the results was lacking. This was primarily due to the small sample size of the test ($n=11$) and even smaller for Prisoner's Dilemma ($n=9$).

The content-validity of the questionnaires, stem from their previous use in related research. The modified GEQ has been used in previous research to report self-perceived group cohesion in a video game context. The GEQ has also been validated through multiple studies [44], [49]. The SPGQ sub-scale incorporated in this study, aims to measure the level of self-perceived interdependence, which relates directly to a core aspect of the O.R.B.S. In addition, the SPGQ has been designed specifically for a video game context. The behavioral markers presented by Truesdell, have also been developed in a video game context. To further improve the validity of the results, all findings of the study are supported by more than one data point, if they are not directly measurable.

A point of contention to the content validity, is the use of the CCSS scores. The CCSS do not pertain to any one field of research, which means its applicability in this context is not necessarily warranted. While the CCSS scores have been treated as intended, for this study, the scores have also been re-interpreted as a dependent score, which may not accurately convey two persons' level of cooperation and competitiveness.

8.2 Methods

8.2.1 Pre-test screening

The purpose of the pre-test questionnaire was to assess each individual's attitude towards cooperating or competing, which in hindsight could have been used to screen participants.

As reported in the Evaluation, section 7.4.1 *CCSS Scores*, group B showed a correlation between cooperative/competitive difference scores (CCSS_COOP/COMP_DIFF) and each individual's interpersonal attraction to the group's tasks (ATG-T). This showed that between each pair, the differences in their attitude to cooperate or compete might have influenced, or at least related to their engagement in teamwork. Group A showed no correlation in the same metrics except COOP_DIFF and ATG-T where medium correlation was found. If the study had implemented a screening process, based on the CCSS results, confounding variables or biases introduced from the disparity between groups could have been mitigated.

8.2.2 Changes in method

The recordings of the play-session attempted to capture both the gameplay and usage of controller in one video, but the usage of the controllers was at times obscured by the participants. For the recording of the play-sessions, two cameras could have been used. One camera recording the participants from the front, which would provide a clear view of the controller usage, and a screen recording of the gameplay. This setup would also allow measuring of mutual performance monitoring, which was discarded for this study due to the limited setup.

Another possible change to the testing method, administering the CCSS in the post-test, could measure the direct effect of the controller at an individual level. Additionally, this would allow for correlational analysis between the CCSS and subsequent questionnaires, without the need to re-interpret the data.

8.2.3 Usability test

In the case of both usability tests, only the O.R.B.S. were tested which resulted in issues with the game at the final test. It was observed in group B that some participants found an unintended strategy, where, instead of timing the required input simultaneously for star combo steps, they rapidly pressed the input button repeatedly. This simplified one of the key interdependent mechanics of the game, and reduced the need for explicit verbal communication. This could have influenced the counts of both explicit and implicit coordination.

Another issue observed during gameplay occurred when participants encountered a shared combo step. The game's logic did not account for the bottom symbol of both O.R.B.S. in that instance, causing the unintended ability to engage multiple enemies at the same time. This inconsistency caused confusion as to the rules of the game and could be a confounding variable, which impacted the results.

8.3 Findings and results

In this study, it was found that the group playing with the O.R.B.S. generally exhibited greater teamwork tendencies. But, the degree of this difference compared to the group that played with gamepads, challenges the applicability of the O.R.B.S. in a real-life context. With such a small difference, is it worth the effort of developing specialized equipment to train teamwork behaviors, and do these differences translate to real-world team dynamics? Would a custom game be sufficient in eliciting and training teamwork behaviors on its own? The results of this study do not point to anything conclusive, but it is a point to keep in mind for further development.

Conversely, customized controllers could aid in addressing weak points in a person's or group's teamwork competencies. The group playing with the O.R.B.S. exhibited a larger amount of explicit, verbal communication, meaning that the O.R.B.S. encouraged a specific type of behavior compared to gamepads. Perhaps, instead of designing a custom controller to help improve collaboration as a whole, multiple types of controllers could be built to address specific teamwork competencies.

9 Conclusion

The project sought to investigate:

“Does a tangible user interface for a game designed to enforce positive interdependence promote collaboration to a higher degree than traditional input systems?”

To facilitate the study, the game SpellBound and a set of custom TUIs (O.R.B.S.) were developed with specific mechanics to promote collaboration and teamwork behaviors. To evaluate the hypothesis, a between-subject comparison was conducted for two groups. Group A played the game with the O.R.B.S., and group B played the game with traditional gamepads. The evaluation method included pre- and post-test questionnaires (CCSS, GEQ, SPGQ), behavioral marker analysis of gameplay recordings and a Prisoner’s Dilemma game.

The results show a low but discernible difference between groups. Generally, group A exhibited greater collaboration than group B. The difference measured between groups is insufficient to disprove the null hypothesis and lacks statistical power to strongly support the hypothesis. It was found that group A exhibited more explicit and verbal communication than group B, indicating that the O.R.B.S. encourages verbal communication. By extension, this suggests that customized controllers can be designed to elicit specific teamwork behaviors.

While no definitive conclusions can be made for this project, the results point to interesting areas of further research, concerning the design of customized TUIs.

10 Future work

Future work could investigate the relationship between player progression and attitudes toward teamwork. In the current study, collaboration was evaluated through questionnaires, behavioral markers, and the Prisoner’s Dilemma, but the analysis did not focus on how far each pair progressed in the game. A future version of SpellBound could log progression data, such as how many encounters were completed, how many enemies were defeated, how long players survived, and whether they completed the game. These data could then be correlated with teamwork-related measures from the CCSS, GEQ, SPGQ questionnaires and behavioral markers. This type of analysis could help determine whether participants with more cooperative attitudes or higher perceived group cohesion etc., would also perform better in the game, and whether this relationship differs between the group using the O.R.B.S. and the group using gamepads.

While this project examines whether a TUI can promote collaboration, future research could focus more on the human experience. One focus could be on how players experience being dependent on another person, since increased communication and coordination do not necessarily translate into a more enjoyable or meaningful experience. It could investigate the players’ opinion of the TUI; Did they find it engaging, frustrating, playful, or enjoyable compared to gamepads? This research angle would have enabled the project to provide a more nuanced social and emotional context, presenting another perspective on whether TUIs could have provided any layer of emotional engagement compared with gamepads.

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11 Appendices

11.1 Descriptive Statistics: Prisoner's Dilemma Scores

11.2 Descriptive Statistics: Questionnaire Scores

	GEQ ATG-T		GEQ GI-T		SPGQ	
	A	B	A	B	A	B
Mean (arithmetic)	7.733	7.760	8.397	7.150	2.950	2.720
Std. Deviation	0.692	1.264	0.373	1.245	0.550	0.466
Minimum	6.400	6.100	7.880	5.250	2.200	2.200
Maximum	8.300	8.800	9.000	8.500	3.600	3.400

Table 12: Descriptive statistics of questionnaire scores

11.3 Mann-Whitney U: Between Group Questionnaire Scores

	U	p	Effect size	95% CI	
				Lower	Upper
GEQ ATG-T	11.00	0.522	0.267	-0.416	0.757
GEQ GI-T	25.00	0.079	-0.667	-0.909	-0.089
SPGQ	19.50	0.462	-0.300	-0.772	0.385

Table 13: Mann-Whitney U of questionnaire scores between groups

11.4 Descriptive Statistics: Paired Questionnaire Score Difference

	CCSS Coop Diff		CCSS Comp Diff		Gaming Hrs/Week		GEQ ATG-T Diff		GEQ GI-T Diff		SPGQ Diff	
	A	B	A	B	A	B	A	B	A	B	A	B
Mean (arith- metic)	0.55	0.40	0.35	1.22	5.50	8.60	0.67	0.72	0.71	2.15	0.42	1.18
Std. Devia- tion	0.31	0.27	0.24	0.48	3.02	3.78	0.53	0.91	0.46	1.97	0.43	0.62
Minimum	0.13	0.13	0.00	0.73	0.00	5.00	0.20	0.00	0.00	0.50	0.13	0.25
Maximum	1.00	0.75	0.64	1.82	8.00	15.00	1.60	2.20	1.00	5.50	1.25	1.75

Table 14: Mann Whitney U of questionnaire score difference

11.5 Mann-Whitney U: Paired Questionnaire Score Difference

	U	p	Effect size	95% CI	
				Lower	Upper
CCSS Coop Diff	19.50	0.460	-0.300	-0.772	0.385
CCSS Comp Diff	0.000	0.008	1.000	1.000	1.000
GEQ ATG-T Diff	18.50	0.576	-0.233	-0.741	0.445
GEQ GI-T Diff	6.000	0.104	0.600	-0.023	0.887
SPGQ Diff	4.000	0.052	0.733	0.217	0.929
Gaming Hrs/Week Diff	8.500	0.256	0.433	-0.247	0.827

Table 15: Mann-Whitney U of questionnaire scores difference between groups

11.6 Descriptive Statistics: Between Group Behavioral Marker Count

	BB		IC		EC		P		A		F		TC	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Median	1.50	2.00	9.50	29.0	58.0	24.00	0.50	2.00	3.50	5.00	2.00	4.00	9.50	4.00
Mean (arithmetic)	1.67	3.00	9.67	27.6	56.7	22.8	1.00	1.80	3.83	4.80	3.00	4.00	9.33	4.00
Std. Deviation	1.37	2.36	6.68	13.3	15.4	3.27	1.27	1.30	1.86	3.56	3.74	1.58	1.21	2.12
Minimum	0.00	1.00	3.00	8.00	30.0	18.0	0.00	0.00	2.00	1.00	0.00	2.00	8.00	2.00
Maximum	4.00	7.00	19.0	41.0	78.0	26.0	3.00	3.00	6.00	10.0	10.0	6.00	11.0	7.00

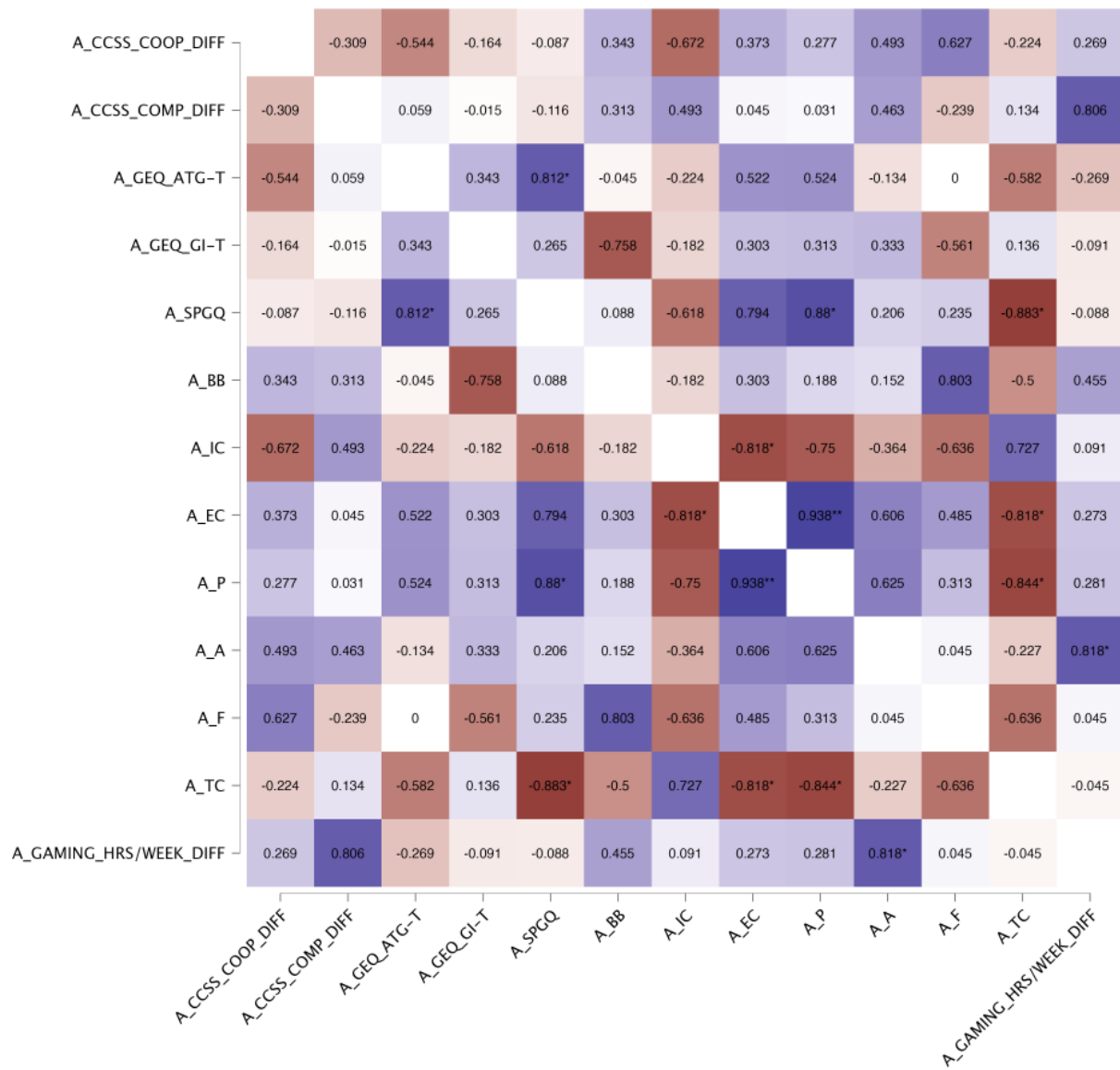
Table 16: Mann Whitney U of questionnaire score difference

11.7 Mann-Whitney U: Between Group Behavioural Marker Count

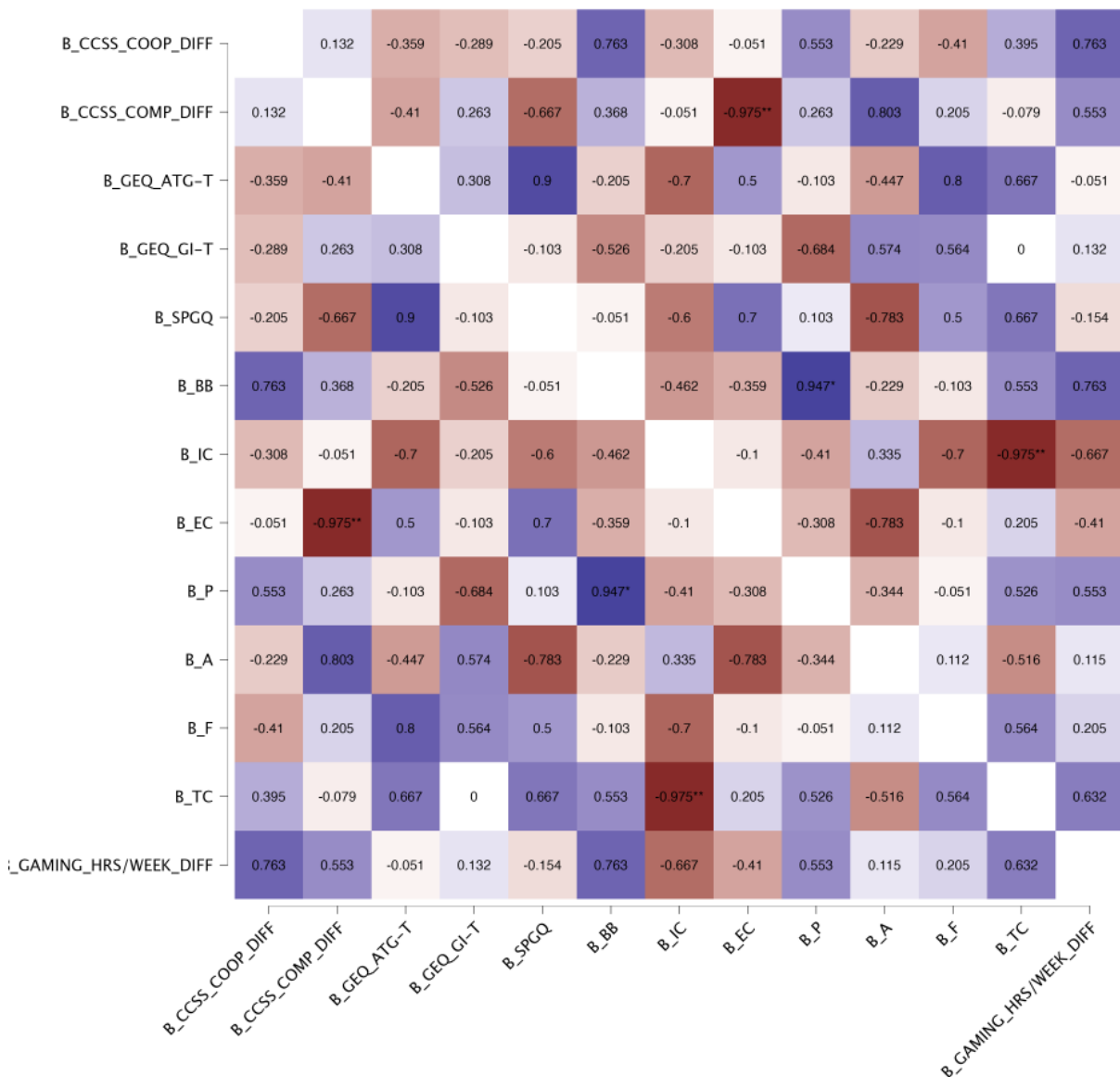
	U	p	Effect size	95% CI	
				Lower	Upper
Backup Behaviors	9.000	0.299	0.400	-0.284	0.814
Implicit Coordination	3.000	0.035	0.800	0.365	0.948
Explicit Coordination	30.50	0.008	-1.000	-0.1000	-1.000
Planning	9.500	0.343	0.367	-0.320	0.801
Adaptability	14.00	0.926	0.067	-0.571	0.654
Failures	8.500	0.267	0.433	-0.247	0.827
Task Cohesion	30.00	0.008	-1.000	-1.000	-1.000

Table 17: Mann-Whitney U of behavioral marker count between group

11.8 Group A Q Score Correlation



11.9 Group B Q Score Correlation



11.10 Cooperative/Competitive Strategy Scale

Questions below are all part of the questionnaire:

1. Individual success can be achieved while working with others
2. Joint effort is the best way to achieve success
3. To succeed, one must cooperate with others
4. Success is only achieved through individual effort
5. Success is best achieved through cooperation rather than through competition
6. In the end, cooperation with others is not compatible with success
7. Shared efforts can lead to both individual and group success
8. I enjoy working with others to achieve joint success
9. It is important to me to do better than others
10. Success is not very important to me
11. By achieving success I also get other things which are important to me
12. To succeed, one must compete against others

13. People who succeed are more likely to have satisfying lives
14. Success is something I am willing to work hard for
15. I enjoy the challenge of competing against others to succeed
16. The rewards of success outweigh the costs
17. Success is my major goal in life
18. I am happier when I am not striving to succeed
19. I feel better about myself when I am working toward success

11.11 Modified Group Environment Questionnaire

Questions below are all part of the questionnaire. Questions highlighted in red are a part of the sub-scale GI-S (social), the question highlighted in blue are part of the sub-scale ATG-T (task), and the rest of the question are a part of the sub-scale GI-T (task):

1. I do not enjoy being a part of the social interaction of this team
2. I am not happy with my level of participation within the video game play and what my responsibilities are during the game
3. I am unhappy with my team's level of desire to do well in this video game
4. This team does not give me enough opportunities to improve my video game play skills
5. I enjoy playing video games with other people more than with this team
6. I do not like the style of how this team plays this video game
7. Our team is united in trying to reach its goals and performance in playing this game
8. We all take responsibility for any loss or poor performance by our team
9. Our team members have conflicting aspirations for the team's performance
10. If a member of our team has problems while they are playing teammates want to help them figure out how to improve their game play
11. Members of our team do not communicate freely about each other's video game play abilities during game play

11.12 Modified Social Presence Questionnaire

Questions below are all part of the questionnaire. The other sub-scalas can be found from the original source [45]:

Behavioural Engagement:

1. My actions depended on the other person's actions
2. The other person's actions were dependent on my actions
3. What the other person did affected what I did
4. What I did affected what the other person did
5. The other person paid close attention to me
6. I paid close attention to the other person
7. My intentions were clear to the other person
8. The other person's intentions were clear to me

11.13 Prisoners Dilemma

11.14 Technical design document

Unity - technical design document

Class InputManager

- Receives input from arduino
- Broadcasts events containing info
- Event1: Player 1 combo
- Event2: Player 2 combo

Sudo code:

```

struct player1
    symb 1
    symb 2
    bool newData

Update()
    player1.newData = Newinfo.Bool;

    if(player1.newData)
        newData = false
        ReceiveInfo()

METHOD RecevieInfo()
    UDP info
    if(playerID = 1 && ReceivedNewInfo)
        structplayer1.symb1 = UDP info
        structplayer1.symb2 = UDP info
        BroadCastPlayer1()
    if(playerID = 2)
        structplayer2.symb1 = UDP info
        structplayer2.symb2 = UDP info
        BroadCastPlayer1()

EVENT BroadCastPlayer1()
    Return Structplayer1
  
```

Class Enemy manager

Enemy manager genererer comboer til hver enemy
 Hver første combo step er anderledes for hver enemy.

Sudo:

enemy manager har liste med alle forskellige start combo.

```
public int[] startCombos
```

```
foreach enemy
```

```
output startCombos currentEnemyStep
```

if første i array hos enemies tag den første i listen

Efter skal enemy have resten af sin combo

Class Enemy

Creates own array called combo array holding values like 1,2,3

always an even numbered array

Even places in the array is a new combo step, **bold** is new step: **1**, 2, **3**, 1, **2**, 3

Variables:

```
Static bool GlobalComboStarted = false
```

```
Bool localComboStarted = false;
```

```
combo array = RandomWomboCombo
```

```
int comboStep
```

METHOD Start

```
Player1Update subscribe to Inputmanager.BroadcastPlayer1
```

```
Player2Update subscribe to Inputmanager.BroadcastPlayer2
```

METHOD Player1Update

```
if LocalComboStarted = false
```

```
if GlobalComboStarted = true
```

```
return;
```

```
if player1Struct.symb1 == comboArray[ComboStep] && player1Struct.symb2 ==
comboArray[ComboStep + 1]
```

```
LocalCombostarted = true;
```

```
ComboStep += 2
```

```
EpicEffects()
```

```
UpdateUI()
```

```
if (ComboStep > comboArray.Length)
```

```
Death()
```

```
ComboStarted = false;
```

```
LocalComboStarted = false
```

11.15 Components table

Components	Reference
M5 stack StampS3 ESP32	[50]
StampS3 Grove Breakout	[51]
WS2812B LED strip	[52]
DRV2605L Haptic engine driver	[53]
2mm mini vibration motor flat coin type ERM	[54]
Rotary Encoder	[55]
3.7v Li-Ion type 16340 battery	[56]

Table 18: Components table

11.16 Worksheets

Worksheets

Week 21

The correlation analysis yielded a lot of results due to its amount of variables and performing it within group A and B separately. Although these results are to be taken lightly we would like to use it as grounds for some points during the discussion. If it cannot tell anything useful about a general group of people, at least it should be able to indicate relationships between variables for this specific group.

Group A

P - SPGQ = 0.88

More interdependence requires more planning and thereby more explicit coordination (P - EC) compared to group B which has no correlation (seen in P - EC)

EC - IC = -0.818

Need for explicit coordination with TUI compared with group B

F - BB = 0.8 compared to B

TUI supports communication and grows with user experience

Group B

EC - COMP = -0.975

Players must reach agreeability in competitiveness to coordinate explicitly

A - Comp = 0.8

Bigger diff in comp scores align with the team work idea of adaptability

A - SPGQ = -0.7

Individual feeling leads to lower cohesiveness and thereby a hard time exhibiting team work behavior... Needs more evidence

F - GEQ ATG = 0.8

The attraction to group might come from common failures instead of directly from controller use.

Game hrs diff - IC and EC = -0.667 and -0.4

Higher diff failed to promote coordination with gamepad as opposed to group a where gaming diff did not have much effect

Game hrs diff - TC = 0.632

Group A & B

SPGQ - GEQ ATG-T = A 0.812 / B 0.9

Link mellem self reported interdependence og attraction til group.

BB - GEQ GI-T = A -0.758 / B -0.526

TC - SPGQ

Gaming diff - BB = moderate positive

Test method improvement as more experienced players might take over. Better screening in the future.

EC - IC = Negative in A group, 0 in group b

Enforced certain type of communication in A. Mixed need for communication in B group (spamming)

P - BB = B high / A low, none

Dont know how to interpret

EC & P - A

More EC leads to more planning and thereby lays the foundation for more adaptability. The prevalence of IC in group B might halt this process.

Adaptability might refer to controller use more than experience as a whole

Gaming hrs diff - post test q scores = very similar relationships (no relationship) between groups. CCSS scores are also similar but not nearly as much.

Descriptive stats: Diff

Mention GI-T diff B

Week 20

Interface performance comparison

A mini game was made to test controller timings.

The process required the user to perform multiple combos on screen as fast as possible.

The initial idea was to use Fitt's law and the index of performance as a metric of performance to compare the interfaces. But as the action of switching symbols on our custom TUI and a gamepad does not align with the calculation of Fitt's law which requires a pointer and target of sort, we could not use it directly. The completion time on symbols however could still be used to compare the interfaces.

Data analysis

Data analysis begins with ordering the data.

This includes:

CCSS Cooperative scores

CCSS Competitive scores

GEQ Subscales

- ATG-T scores
- GI-T scores
- ATG-S scores (For this, only two items are used and does therefore not hold any validity)

SPGQ scores

Prisoner's dilemma (PD) scores

Behavioural marker (BM) count

The plan for analysis is to compare the two groups using a Mann-Whitney U test and calculating the effect size to spot any difference. We would also perform correlation analysis. These would have to be performed within group as between group correlation would analyse the game and not the controllers.

Ordering data met its first obstacle as PD (Prisoners Dilemma) is a pairwise score. PD scores are each participant's individual scores summed. BM (Behavioral Marker) count is within pairs during game play sessions.

This led us to pair the Q score data within groups as they also aren't independent but have a different combination of participants than the PD scores.

In sum: Q scores are averaged within game play pairs. BM count totals are the sum of participants within pairs. PD scores are summed within the pair that played against/with each other.

This means correlation is not possible between PD scores and the rest of the data.

The proposed method of analysis are:

Descriptive statistics to compare means between groups.

Mann-Whitney U test to calculate difference between groups and their scores.

Correlation to find meaningful relationships between Q scores and behavioural markers.

These seem to be the best statistical tool of analysis for our case, however the small sample size does interfere with the reliability of our study and must be taken into account when presenting our findings.

Week 19

Most tests were conducted this week.

The first day was used to recruit participants.

Subsequent days were spent facilitating tests.

Week 18

Final test procedure has been decided. After consulting our supervisor we discussed the following test procedures:

Physical controller game (PCG)

Default controller game (DCG)

1. Within group

Collab test → PCG → collab test → DCG → Collab test

(each collab needs to vary so they can't just learn how to do it correctly)

2. Two groups

Pre-test → PCG → Post test

Pre-test → DGC → Post test

3. Something

Entire group → 2 half groups

Day 1

1-Half → Pre-test → PCG → Post test

2-Half → Pre-test → PCG → Post test

Wait 2 days:

1-Half → Pre-test → DCG → Post test

2-Half → Pre-test → DCG → Post test

Procedure:

We decided to go with number 2, **Two groups**. Partly because the other options would require significantly more time.

We decided not to do prisoners' dilemma before having them play, as it might create bias and could prompt them to do better in post-test. Imposing a possible confounding variable.

We chose to do GEQ (Group Environment Questionnaire) after them playing as it would require a prior social relationship and a common task/game to perform. Instead, the CCSS questionnaire was used for the pre-test as it could indicate their competitive and cooperative attitudes.

Unity

Boss battle

A final boss battle was implemented as a way to end the game. The boss has a 15 step combo and is constantly firing projectiles. This puts a lot of pressure on the players to both communicate and input the correct combo steps quickly. Additionally, the projectiles sometimes block the view of the boss' combo, requiring quick completion of them.



Sound.

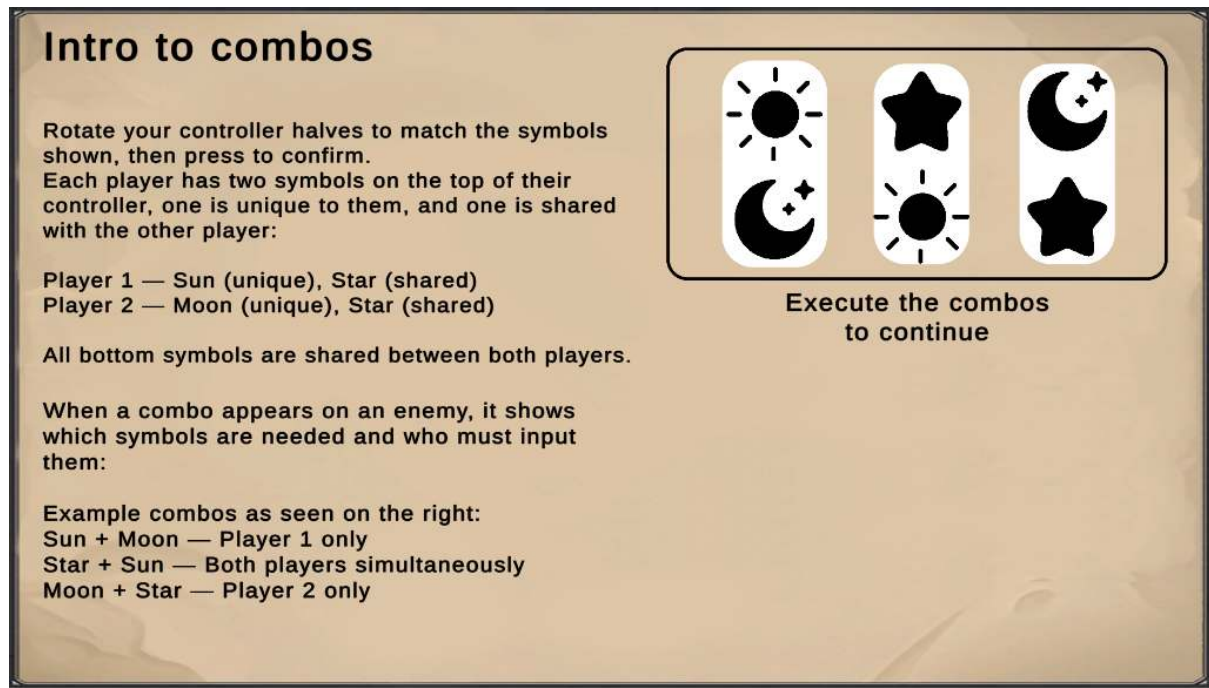
Added all sound around the Boss encounter, and did a final polish of the sound in general.

Week 17

Completed usability test on three persons. We decided to add a boss fight as the last enemy encounter to have a more “real” ending for the game, as well as putting more pressure on the players to hopefully play better together and communicate.

Tutorial implemented

The tutorial was implemented and served several purposes; to have the information the participants from the game be consistent from test to test and to ease them into the otherwise difficult control scheme on both TUI and gamepads.



Visual of the first section in the tutorial describing the combos and controls.

The tutorial is divided into 4 sections, each describing their own respective function in the game:

- Firstly information on the controls from both the TUI's and the gamepads was explained, as well as establishing the game rules such as the players has to press a combo that starts with star at the same time, and also giving them instruction on which symbol each player has.

The second section informs the players about the rules of target selection for enemies, where you cannot change targets when you have already started on one.

The third explains projectiles, which has the rule that they can be targeted whenever the players want to.

The fourth one describes the special ability the players get access to when having completed enough correct inputs in a row.

The tutorial could be further polished as we found out that the usability scores dropped when players had a tutorial instead of just us explaining the process and game rules before starting the game.

Sound

Designed and added sound effects to the special attack. Also added minotaur footsteps, and enemy projectile sound.

Week 16

Unity

We added some more VFX to the player's spells. This included the damaging spell randomly choosing between a fireball and lightning bolt.

A special ability was added which shoots a ball at the current targeted enemy, and kills it regardless of where the players are in its combo. It serves as a way to reward players who do not spam wrong inputs, but carefully choose the correct combos.

As both of the TUI balls had been created, we started internal play testing the game with the balls, in order to ensure things worked as intended. Setting the system up and getting it ready for usability testing the next week.

Sound

Sound implementation was also started utilizing Wwise as the middleware for all sound in the game. Environmental atmosphere, music and critical sfx was the main focus this week. Wwise was chosen due to the sound engine's event centric design where a sound is called in game but where all the attributes are controlled in the Wwise editor. This makes the implementation faster once setup is complete and gives us more freedom to create the soundscape we wanted. Furthermore Wwise is the standard in the industry so getting to know it was a big decision factor as well.

Usability test

Finished the last usability tests. Tested 4 pairs in total with generally good feedback, most data was observational apart from SUS questionnaires.

The main take away was that the game was too short.

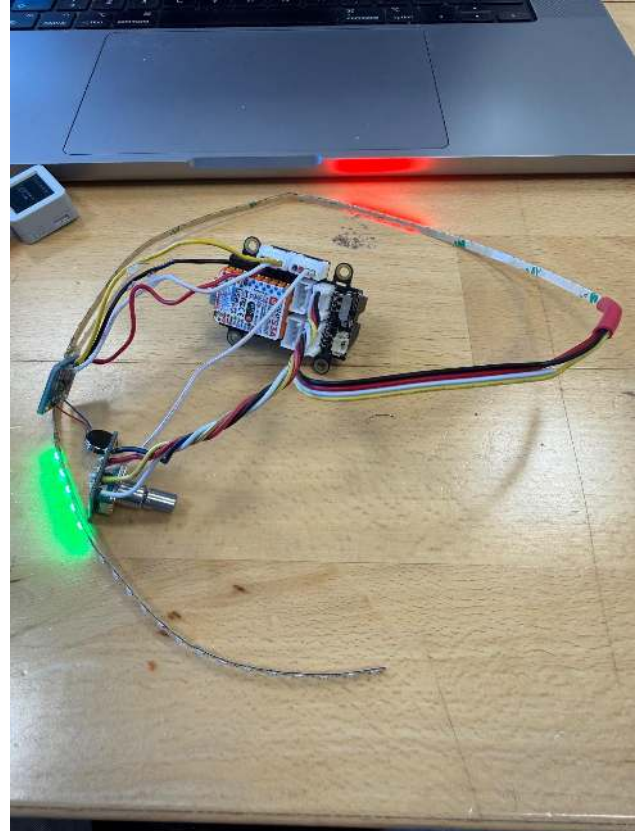
The to-do list based on the usability test:

- Extend game playtime by adding more content.
 - For the final test the door opens and continues inside the castle. There were more difficult encounters with longer combinations and more enemies.
- Create a tutorial so test facilitators don't have to explain game mechanics.
- Make locked on enemy stand out more/
-

Week 15

Controller

The design is now finished and focus is on finalizing the software.
Started replicating everything into controller two.



Week 14

- Wrote a little on the report, polishing analysis section.
- Worked on semester course projects.
- Easter holiday :)

Week 13

Defining end result: Collaboration vs. Cooperation

<https://journals.sagepub.com/doi/epdf/10.1177/0149206320901565>

Through the lens of interorganizational relationships this paper proposes a definition of the terms coordination, cooperation and collaboration and how they are connected, by defining dimensions that outline the meaning of each term. Coordination concerns itself with parties agreeing on goals while cooperation focuses on carrying out said goals. This falls within the discriminating dimension's temporal stage which marks the difference between deliberation and decision phases. Collaboration on the other hand is again defined by the discriminating dimension's goal types, distinguishing itself from the previous terms by defining which type of goals are prioritized (common/private goals) and the willingness to help other partners achieve their personal goals as well as common goals.

This distinction allows the proposed methods of evaluation (GEQ and Prisoners dilemma) to continue as planned. While not properly defined, in this paper

(<https://onlinelibrary.wiley.com/doi/full/10.1002/ejsp.1940>), its use of the word cooperation does elicit a similar meaning to how collaboration is defined in the previous paper in regards to its use of evaluating with the prisoners dilemma game, it contradicts it in regards to its testing conditions with the use of Mario Kart, as the conditions of the game does not afford the players to have any private goals.

While these definitions are hard to pinpoint another guiding factor for our research comes from this paper

(<https://www.sciencedirect.com/science/article/pii/S074756321530159X#bib118>).

This puts the three terms previously mentioned under the category of teamwork competencies.

As another systematic review, that seeks to clarify which game attributes influence the features that promote these teamwork competencies, an array of research has been used to guide the coupling of attributes to competencies. Choosing a definition to base our research on will come from the Castaner and Oliviera paper and subsequent literature will fit its definition into this.

As teamwork exists as a broad term and also needs a clear definition, Salas

(https://www.researchgate.net/publication/220041354_Is_there_a_Big_Five_in_Teamwork)

sought to define its five core components.

- **Team leadership** does not have much relevance for this project and will not be mentioned as game mechanics do not promote leadership.
- **Mutual performance monitoring** concerns itself with having participants caring for each other's work as well as their own. It requires a shared mental model (knowledge of each individual's tasks) and a trusting climate.
- **Backup behaviour** seeks to manage workload imbalances by either coaching, assisting with a task or taking over the work.
- **Adaptability** means adjusting a plan to compensate for deviations.

- **Team orientation** is not behavioural like the latter concepts. It is attitudinal and facilitates the previous concepts by looking at a participants input and prioritization towards individual and common goals.

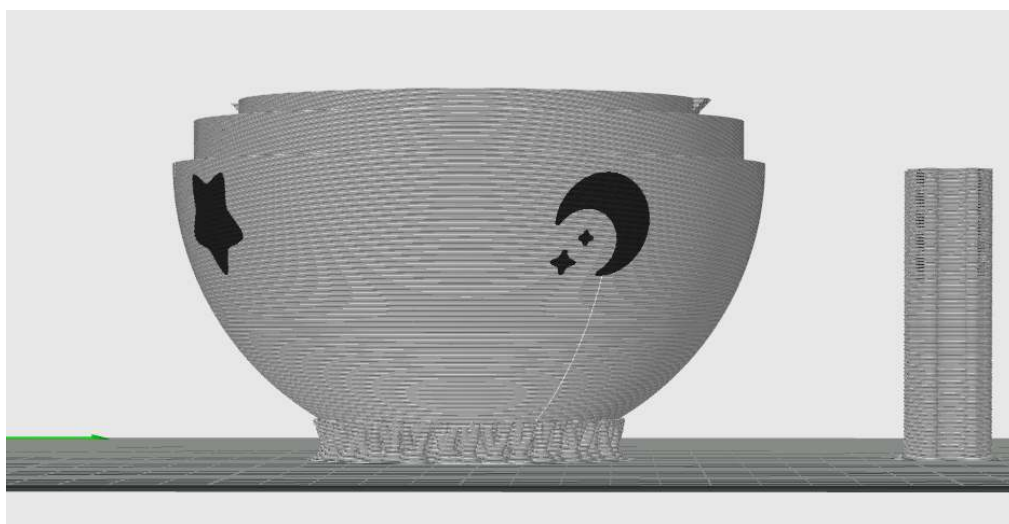
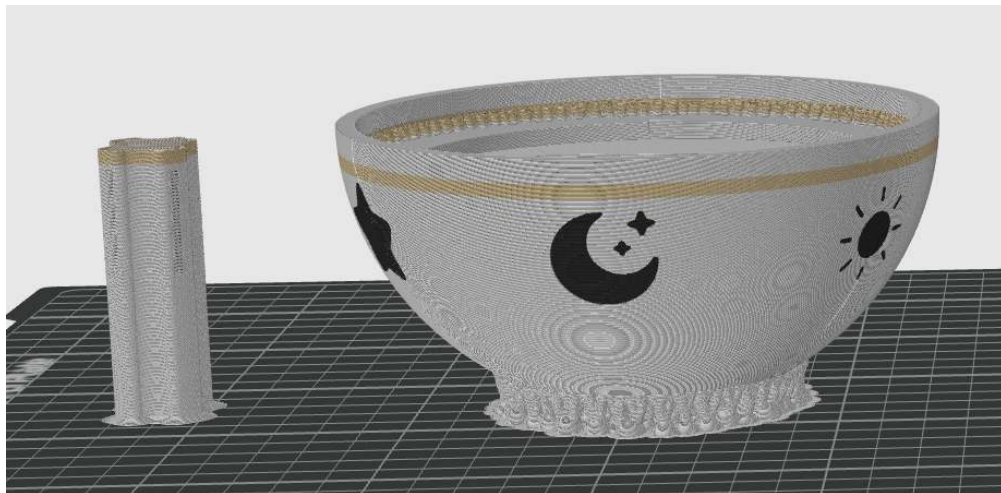
Underneath these components lie three mechanisms that facilitate the previous five.

- Shared mental models, common understanding of goals, roles, etc. “Team-related mental models have to do with the team functioning and expected behaviors, whereas task-related mental models contain information regarding the materials needed for the task or the manner in which the equipment is used.”
- Closed-loop communication (figure in paper) ensures clear communication. Is not regarded as useful since one component of the big five, team leaderships, won’t be prevalent.
- Mutual trust

Controller

We made final touches to the design, including a transparent layer for an LED ring.

A full functional version one was printed using AMS automatically shifting between colors:



Unity game development

1. Creation of game world and visual style

The visual style was decided upon at the beginning of the week. An asset from the unity asset store was bought and imported into the project. The asset contained a demo scene which we decided to copy and use as a starting point for the level.



A rough layout of the path system was laid out throughout the world as well as the sequence of enemies that the player would have to complete was laid out.

Week 12

Controller

Worked on redesigning and refining the internal component placement.



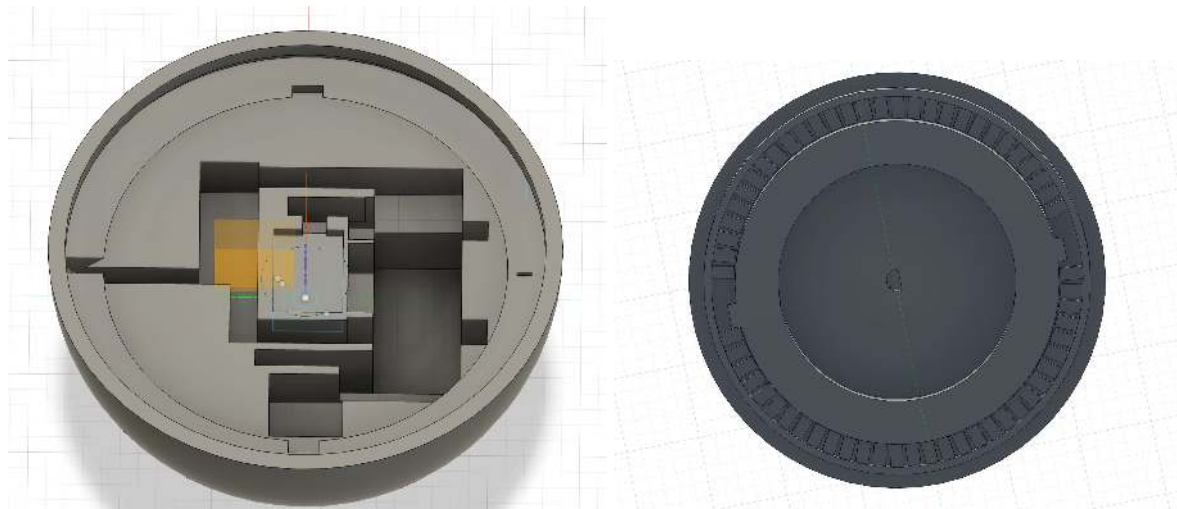
Started working on haptic feedback:

Decided on using a LRA Haptic motor and a DRV2605L haptics driver for feedback when the button was pushed.

New encoder:

The rotary encoder that was used had a push button feature which we found did not work as intended. A new model encoder was found with a dedicated push button pin.

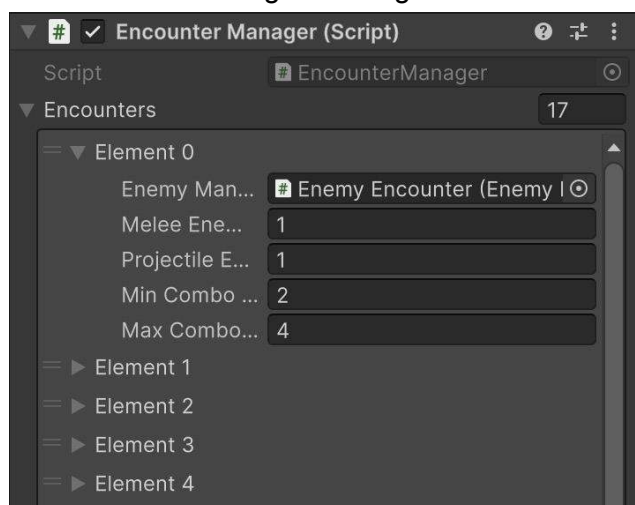
Controller final design



Unity game development

Further development of digital prototype:

1. Enemy system development
 - a. The enemy spawning system was further developed, to also incorporate an [EncounterManager.cs](#). This script tracks the player's current progression, and uses it to trigger the corresponding [EnemyManager.cs](#) script, which contains relevant information for each encounter. [EncounterManager.cs](#) maintains a list of [EnemyManager.cs](#) to manage this across all the different encounters throughout the game.



For example, the encounter visible in the image, will spawn one melee enemy, one ranged, and the combos to kill them will be a minimum of 2 and maximum of 4 in length.

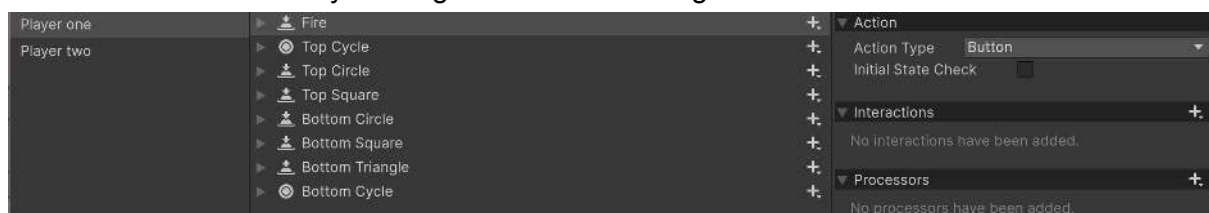
2. Visuals style agreement
 - a. It was agreed that the game world should be set in a medieval setting and use a semi-realistic environment package.
3. Player path
 - a. We also started moving the players between the Encounters using a Bezier Paths unity asset.
4. Enemy model imported.



Week 11

Development of digital prototype in detail:

1. Enemies systems
 - a. The Enemy system entails an EnemyManager.cs and [Enemy.cs](#). The EnemyManager handles spawning the enemies at different locations in the world, each spawned enemy has their own [Enemy.cs](#) script attached as a component. The [EnemyManager.cs](#) also handles assigning a combo to each enemy ensuring each of the combos are unique. [Enemy.cs](#) handles their own ui's describing their combos for the player to execute as well as removing the combos as the player completes them. [Enemy.cs](#) also sets up the basics for the navmesh agents to walk towards the players and damage the players when they are close.
2. Input systems
 - a. The project utilizes unity's input system. The input action asset contains action maps for both players that are spawned into the game at runtime. The inputs are registered by an input manager that keeps track of both players' current inputs, being the symbols they have chosen. These inputs are then broadcast to enemies through events that are available project wide for other systems to subscribe to.
 - b. The game is made to work with gamepads and keyboards. The physical controller and inputs from it are yet to be set up as the specifics of the controller is not final yet.
3. UI
 - a. UI for each player was set up to display their active symbols. They mainly served as a debugging purpose and it has not been decided whether these should stay in the game for user testing.





The image depicts the first prototype of the game, showing enemies approaching with distinct color variations to aid differentiation. The UI also shows the health system and each players' chosen symbols in both the bottom-left and bottom-right corners.

The prototype was deliberately styled as cartoonish, as it allowed for rapid and straightforward prototyping. The scene was constructed using simple Unity 3D box primitives, using a toon shader and an outline shader. While prior discussions had pointed toward a higher-fidelity aesthetic, one more grounded in a medieval fantasy look, we were not certain whether that direction was worth pursuing given the potential longer implementation time.

Controller

We began putting together the electronics and started modelling how they would fit inside each controller.

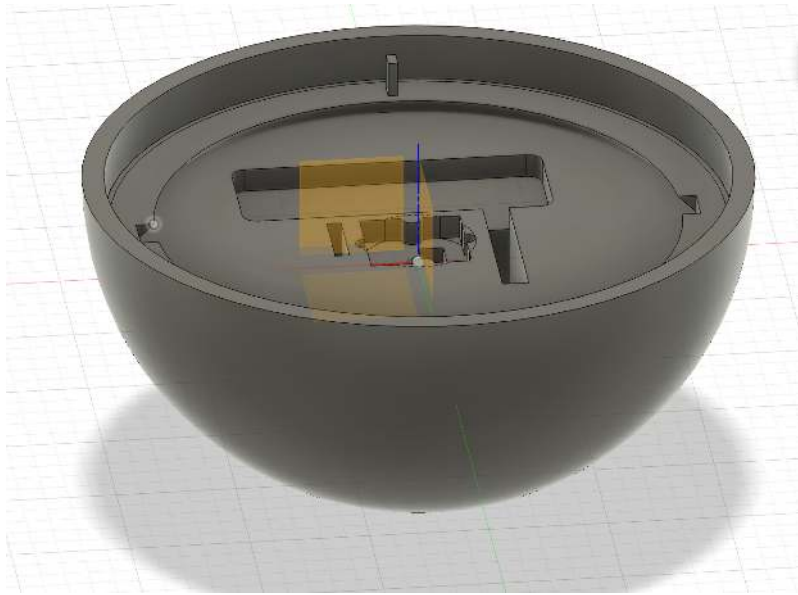
The components used :

Esp 32 Thingplus S2

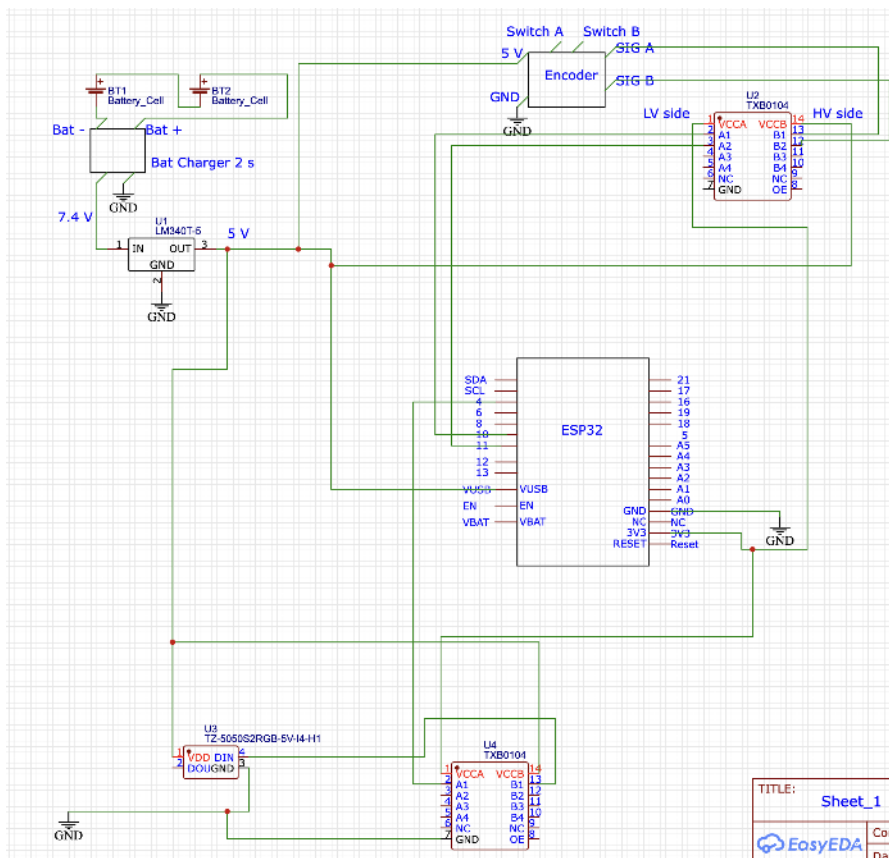
Grove Encoder seedstudio with pushbutton

Led light strip (WS2812B)

Additionally, space for a IMU BNO085 was made, if the need was found for it later in the process.



During the process of implementing the battery, we found out that everything else but the ESP thingplus requires 5 volts. This meant that we either needed a voltage regulator to boost 3.7 V (from the li-po battery) up to 5 volts or use two 3.7 batteries in series which would provide 7.4 volts that then needed to be regulated down to 5 volts. Both scenarios would require a lot of extra work and the space inside the sphere was also a concern. We initially went with the 7.4 V down to 5V solution and made a schematic to visualize it.

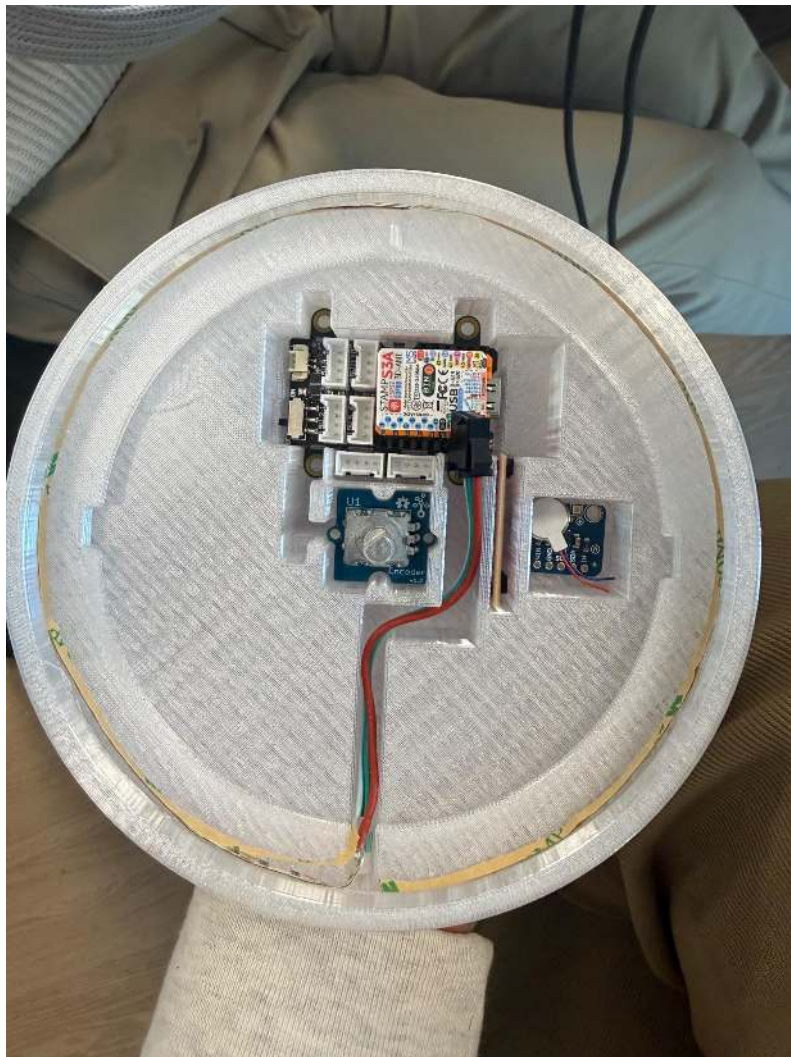


In the process of redesigning the lower body to fit everything and finding a charger that can manage two Li-PO batteries, we found a different solution. By using the StackM5 ESP StampS3 and the M5 Grove breakout we solved the following problems:

- 3.3 → 5 volts conversion, as the grove had a built in booster.
- There was space for a 16340 type Li-ion rechargeable battery.
- It uses grove connectors, eliminating the need to solder anything to the microcontroller itself.

Stamp-S3 GroveBreakOut

SKU:A144



Week 10

Paper prototypes were tested:

1. Enemies approach with random combos to execute. Player 1 can only execute steps starting with squares and circles, player 2 can only execute steps starting with squares and triangles. Testing 3 pairs, we found that there was a moderate amount of communication between players. We felt that this did not support cooperation enough as they would just press their respective combos without really thinking about it. Therefore we changed the game mechanic of how to execute steps. Players now have to simultaneously execute the square steps which we hoped would create more room for communication. We also added a permanent healing combo with only squares on top, that should be executed simultaneously by both players.



Greyboxing and wizard of oz

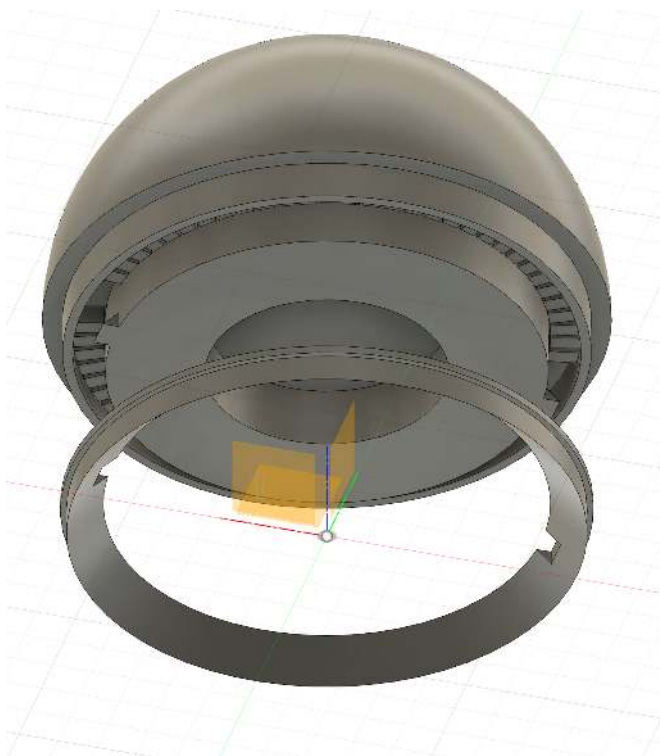
A Unity greyboxing prototype was made where enemies spawn with random combinations. They could then be clicked with the mouse pointer to clear a combo step, which was used for wizard of oz testing.

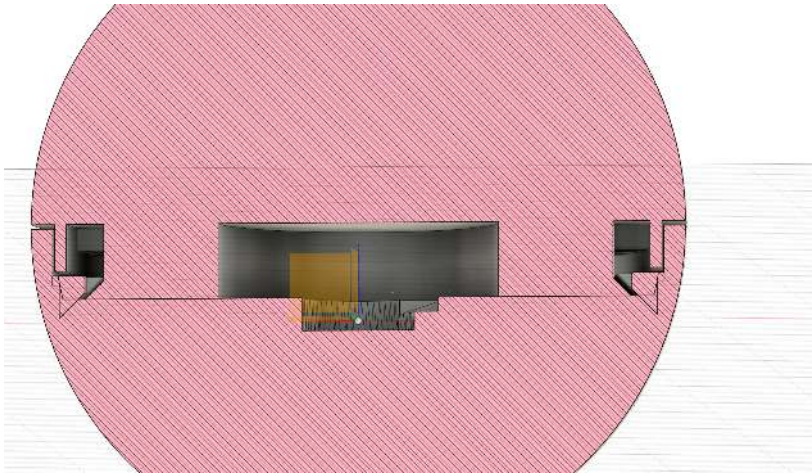
Controller

Worked on the locking mechanism so the two sphere halves don't split while playing. The idea is a lock that goes in a groove on the inside lower half.



After some test prints this solution was not feasible as the pins would break due to weak bonding of the PLA layers. Instead we went with a solution where we created a curved groove locking mechanism that worked better. We also changed the internal spourgear to create the click sound to small lines in the top that a pin would run over to create the sound instead.





Week 9

Chosen final direction for projects.

Started developing game mechanics through paper prototyping.

Made paper prototypes:

- v1 was tested, they said it was fun

- v2 had color,

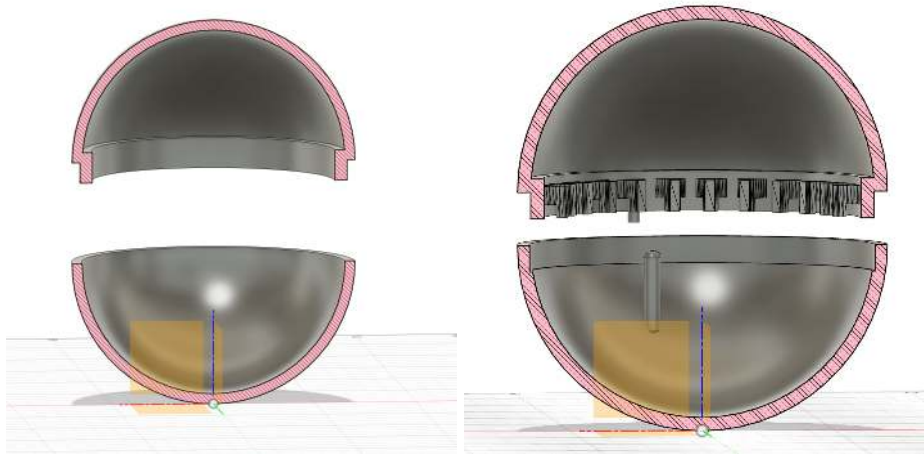
Informal testing of paper prototype.

Began writing analysis.

First version of evaluation method developed.

Started working on the controller 3D model.

Idea was a sphere you can spin, turning a potentiometer inside, with clicking sound for each spin increment. Started with a diameter at 120 mm but after a testprint we decided to scale it up to 140 mm. Added Internal spurgear to create the clicking sound with a pin on the lower sphere half.



Week 8

This week we categorized the papers and research found into relevant topics of the analysis. Currently the following are topics of the analysis:

- Teamwork research in computer games
- Teamwork research where participants know each other
- Teamwork research where participants don't know each other
- Tangible interfaces
 - Teamwork/collaboration with tangible interfaces
- Teamwork and teamwork behavior
- Evaluation methods of teamwork

Need:

Further research on the topics of teamwork,

Further research on evaluation methods.

- Cohesion questionnaires.
- Prisoner's dilemma.

Discussions on focusing on collaboration or teamwork, and their differences

We have a current outline of evaluation, based on the "There is no I in team" paper, and some others. Current outline:

- Observations of teamwork behavior during gameplay (based on consistency of teamwork behavior in gameplay paper)
- GEQ - questionnaire measuring team cohesion (based on there is no I in team)
- Prisoner's dilemma variant

This would help triangulate whether teamwork behavior was present.

We found that more papers than expected had research where participants didn't know each other. We plan to keep the direction of participants that don't know each other as a validity strategy, and then focus on the problem statement of tangible interfaces in computer games, and if it can foster teamwork behaviors.

As we looked into observations as an evaluation method, we discussed contacting Carlos for some guidance on the topic and how to do it properly. It is still not certain whether we move forward with this or not, also based on Ivan's feedback, suggesting not doing observations.

Week 7

Decided to focus on teamwork research where people don't know each other.