Using Modern Technology for Combinatorial Boardgame Design and Discovery

Bas van de Weerd

Creative Technology

Graduation project

Supervisor: Gerhold, Marcus, DR., Bults, Richard, ir. ing.

Critical observer: Ahmed, Faizan, DR.

Date: 21/07/2022

Abstract

With a steady growth of market share, the boardgame industry remains an interesting field. Designing boardgames is a very time-consuming process. This thesis aims to find ways to reduce development time of new games by automating this designing process through modern technology.

First a literature review was done on preexisting work about randomly generating games and factors that could be measured to predict the quality of a game. A game design process was ideated that uses artificial players for playtesting games. A game was developed for evaluating this process. After using the new design cycle a playtest was conducted using human players.

Although no strong conclusions can be draw about the correlation between the correlation of perceived difficulty and enjoyment. Perceived difficulty still plays an important role in whether someone will like a game or not. Ultimately, complete automation of a game design process was not achieved. Using artificial intelligence for playtesting games seemed to be a successful tool in reducing game development time.

Contents

List of figures

Chapter 1 -Introduction

1.1 Background and Challenges

The boardgame industry is predicted to keep growing for at least the next years [1]. One of the main contributors to this growth is the COVID-19 lockdown restrictions causing an increase of demand for indoor activities. With an increase in market share the desire for new boardgames is also growing. Designing boardgames still is a very time-consuming task that requires a lot of manual labor in the form of re-designing and playtesting. With the current technology it is possible to automate a lot of processes with the use of Artificial Intelligences. Therefore, the boardgame industry might greatly benefit from an AI driven automated game design process. Reducing both development costs and development time.

Besides reducing development time and cost, certain board games are so popular that the existence of them is seen as common knowledge, take tic-tac-toe or chess as an example. This could support the existence of other not yet discovered high-quality games which are fundamentally well designed, or at least something that makes them widely appealing, much like mathematical formulas that have also independently been re-discovered. Automating the design process of boardgames could lead to the discovery of yet undiscovered high-quality games. Despite all the AI advances, game design is a discipline/profession that requires a lot of human input due to being highly artistic. This makes determining the quality of games a hard task to automatically do. However, with the use of simulations using artificial players it could be possible to make an approximation of the quality of games, reducing the human input in the development process. This approximation could be based on certain parameters or artificial player behavior that are fundamental to these games, which are determined by simulating the game.

1.2 Research questions

The main question that is going to be answered within the scope of this thesis is:

How can modern technology be used to automatically generate and evaluate (combinatorial) boardgames?

The term high quality within the context of this report is focused on the enjoyment and complexity of these games. The definition of these terms is elaborated more in the background research (chapter 2).

From the main research question two important sub-questions follow:

SQ1: What factors could be used to determine or predict the quality of a boardgame?

SQ2: How can modern technology be used to automatically generate any (combinatorial) boardgames?

1.3 Combinatorial games

The term combinatorial in the research questions is put inside of brackets as the main goal of this project is not to specifically look at mathematical or combinatorial games. For improved readability and clarity combinatorial games will often be simply referred to as games in this thesis. Combinatorial games are games that are most looked at in the field of mathematics. Combinatorial games are turn based 2 player games like chess, checkers, go or even tic-tac-toe. Combinatorial games contain no randomness besides determining the starting player. These games also have no hidden information to either player. Not involving randomness in games makes them significantly easier to analyze and the goal of research done within this field is often to 'solve' these games. The games that will be developed within this project will most likely fit the criteria of being combinatorial games. A game is solved when an optimal winning strategy for these games is determined. Because these games can be solved, these games arguable are not actual "games" anymore, as seen through the lens of modern game design. However, even with modern computing power it is still not yet possible to solve some of these games. Therefore, this field remains to be explored by mathematicians.

Chapter 2 - Background Research

It is of use to first take a more in-depth look at existing literature that something like the goal of this project. Furthermore, the analysis of previous work will reassure that this project will contribute something new to existing work. A lot can be learned from the approaches and findings of other authors. Doing this the focus will be on the answering how a combinatorial game can be randomly generated using modern technology.

Besides looking at similar projects a literature review was done on engagement and enjoyment in boardgames. This was done to focus on sub-question SQ1. Determining what makes games enjoyable from a user's perspective, contributes to answering this sub-question. First an overview will be given of research and articles about engagement in video games. Next, the findings will be compared to see what similarities and differences are present about the engagement and enjoyment of playing games. Finally, a conclusion will be given of the elements derived from this research which could contribute to predicting the quality of a game.

2.1 Literature Review - Introduction

The gaming industry is a large and competitive growing market. Coming up with good quality novel games is a difficult task. Although it is possible with current technology to automatically generate combinatorial games, determining the quality of such automatically generated games still serves a complex challenge. Being able to automatically detect or predict the quality of a game is the missing piece for effectively generating new boardgames, which could save a lot of time and resources in the development of new games. However, not much research has specifically been done on the measurable aspects of combinatorial games that can help predict the quality of a game or quality of engagement [2]. Therefore, the goal of this section is to give an overview of research about user engagement when playing games and using that literature for determining what possible measurable components a combinatorial boardgame might have that could say something about the quality of the game. Theory for both digital and physical game design will be included in this review.

2.1.1 Engagement

To get a better understanding of the term 'engagement' let us first define it Within this thesis the term engagement will be defined as: two-way interactions between consumer and the (video-) game product, with varying modes of consumer engagement such as cognitive, affective, and behavioral. This definition is close to the definition used by Abbasi et al. [3] and the definition used by Banyte et al. [4].

These engagement modes are affected by how the user experiences a certain activity. A model was made by Abbasi et al. [3] to predict consumer engagement in video games. This model was empirically supported based on data collected from 436 teenagers. Their model suggest that engagement is derived based on the experience, which can be broken down into three categories. The first category is the imaginal experience, the second category is the emotional experience, and the third category is the sensory experience. When comparing these categories to the definition of engagement given above, they appear to be closely related to the three different modes of engagement.

There has yet to be developed a standardized way to measure the quality of engagement. This is also pointed out by Elena et al. [2] in the field of serious games. The goal of this research was to improve the overall engagement of serious games. A similar conclusion was made in a literature review conducted by Bakhanova et al. [5]. However, this research focused more on the enjoyment of the gaming experience rather than the educational aspect of serious games. They discussed that a standardized way to measuring the quality of games as an experience is hard to implement as the factors that play a role differ between game platforms. The continuous development of more of these platforms make the issue of obtaining a standardized way to measure the quality of an experience increasingly more difficult.

Whilst it is hard to measure the quality of an experience, it is possible to measure how deep a user is engaged in playing a game. Brockmyer et al. [6] were able to measure how deeply engaged users were when playing a game with the use of questionnaires. This questionnaire relied on the theory of flow introduced by M. Nakamura Jeanne and Csikszentmihalyi [7]. Flow occurs when someone is engaged in an activity with the right balance between skill and challenge.

2.1.2 Enjoyment

How engaged the user is in playing a game is not the same as measuring the quality of the engagement. While it is possible to measure how engaged a user is in an activity, as found by Brockmeyer et al. [6], there is currently no way to determine the enjoyment of engaging in playing a game during play. Measuring where and when a user experiences fun while they are playing a game was said to be an arguably impossible task by Laffan et al. [8]. The goal of this study was to find how engaging in video games changes one's overall general happiness. Ultimately, it could not be concluded that engaging in video games has either a positive or negative effect on overall happiness.

Looking more on enjoyment whilst participating in games, a study by Pienimäki et al. [9] found that experiencing fun differs per person and is dependent on the context of the experience. This could contradict the existence of fundamentally enjoyable aspects of a game. However, this study was done on educational games played in large classrooms or groups. Although there are some similarities between group experiences and more personal experiences, this does not disprove the possible existence of fundamentally enjoyable aspects of a game.

2.1.3 Motivation

There is a strong connection between consumer motivation and engagement. Motivation is needed before a user engages in a certain activity. Three levels were distinguished that influence the motivation of the consumer or user in a framework constructed by Banyte et al. [4]. The strongest being described as presence. This presence refers to the consumers' awareness of time passing or automatism in playing. The second and weaker level is the intrinsic motivation, which can be described as the user's immersion while playing a game. The last and weakest level being extrinsic motivation, which refers to elements of the game itself.

2.1.4 Attention

Another factor required for engagement in games is the user's attention. Kniestedt et al. [10] introduced a model for analyzing and improving applied games. The core values that can be taken away from this model is that a user's attention, which is needed for proper engagement, is a limited resource. This resource is spent less quickly once the user obtains automation of play. This ties in with the aforementioned presence of a game. For boardgames the user should keep their attention mostly to playing the game to keep the user engaged until the game is finished. The game length therefore could be a factor for determining the quality of a game. However, this does not mean that a longer game is worse than a shorter game because this resource is consumed less quickly when automation of play occurs.

2.1.5 Difficulty

The difficulty of a game also plays a role in the engagement of a user in the game. Kafai [11] mentions in his book about computer child interaction that presenting a challenge in game context motivates users to try again to succeed, thus keeping them engaged for longer than with an easier challenge. The user will spend more time on a challenge if, after failing, the users still feel capable of solving the challenge and is given the opportunity to try again.

The findings of Kafai [11] do not carry directly over to the context of a boardgame. This is because most boardgames are not meant to be solved or “beaten”. The challenge mostly resides within the skills of the opponent the user is playing against, which is not a measurable quality of the game itself. For predicting the quality of a game this means that players of the same skill should be used for testing. One or both players could be replaced by an Artificial Intelligence player. With two AI players of the same skill level, an unbiased prediction could be made without including the difficulty that comes from skill difference between players.

2.1.6 Conclusion and Discussion

Although engagement can be broken down into three modes of engagement: cognitive, affective, and behavioral [3], [4]. It is still hard to measure the quality of engagement for playing video games. However, it can be measured how deeply engaged the user is engaged while playing games. To make the user more engaged in a game the theory of flow [7] can be used. The user is more engaged in an activity they feel competent about but also is challenging enough not to feel boring. Although with the use of this theory it can be measured how deep the user is engaged in playing a boardgame, how deep the user is engaged does not necessarily say anything about the enjoyment of the engagement.

Where enjoyment comes from while engaged in games is mostly a personal matter. This is supported by the findings of Pienimäki et al. [9]. This is also supported by the theory on motivation by Banyte et al. [4] With the intrinsic motivation differing from person to person. The presence and extrinsic motivation combine to form the context of a game. Based on this connection the presence (e.g., awareness of time passing and automation in playing) of a game therefore influences both the enjoyment and motivation to keep engaged in playing a game. Although enjoyment of a game mostly is a personal matter there are some aspects like presence that makes some games fundamentally more enjoyable than others.

Based on the aspects that play a role in the enjoyment of being engaged in playing a game, some measurable aspects that could be used to predict the quality of a boardgame can be hypothesized. One of these aspects could therefore be linked to the number of options or complexity a player faces while playing a game. The goal of this aspect would be to find the right balance of complexity to improve the presence of a game and making it easier for automation of playing a game. Another area where these factors could be present is the difficulty of a game. It could be of use to look at simulation outcomes using different difficulties of virtual players. While there are some assumptions to be made based on the findings of this literature review all these assumptions must be tested in practice to show whether they can truly be used for predicting the quality of a game.

2.2 Determining quality

One of the findings of the literature review is that the difficulty of a game plays a big role in the enjoyment of the player. There are two main factors that make for the difficulty of an individual game. The first being the skill of the players. A player playing against a much higher skilled opponent will experience the game as more difficult than vice versa. The other factor being the difficulty, or complexity, of the game itself. The difficulty and complexity of a game are determined by multiple factors. A big factor that determines the complexity of a game is the number of rules a player hast to learn for them to be able to play the game. Another one of these factors is the possible moves a player can and must take into consideration, both their own moves and their opponents'.

The difficulty affecting the engagement of the user ties in with the concept of flow created by Nakamura Jeanne and Csikszentmihalyi [7]. This concept states that the best type of engagement is when the user enters a flow state. In this state the user feels the task is challenging enough to not feel boring, but the user also is and feels competent enough to complete the task.

2.3 Evolutionary Game Design

Automatic generation and evaluation of boardgames has been done before in the paper "Evolutionary Game Design" by Browne et al. [12]. Their focus was to discover new games that could become the new "classics" such as chess, checkers or go. They also focused specifically on finding combinatorial games.

For determining the quality of a game, they came up with a list of 57 criteria. These criteria were separated into three types: intrinsic (16), quality (30) and viability (11). With *intrinsic* they refer to the rules and equipment of a game, with *quality* the measurable criteria during play were covered, and with *viability* the criteria obtained from outcomes of play. A correlation between the factors and the likability of a game was determined with the use of surveys. These correlations of the factors and the likability of a game were then later used for predicting the quality of automatically generated games.

The list of categories distinguished by Browne et al. [12] is very much based on what aspects can completely automatically be measured within boardgames with the use of simulated play sessions. Within this graduation project determining these aspects will be approached differently. Instead of focusing on automatable aspects that can be measured, the focus of this thesis partially lies on the latter part of their study. In this thesis a look will be taken at previous research about engagement and enjoyment in video games. Based on those findings, measurable or observable aspects will be hypothesized that could be used for predetermining the quality of a game, instead of the other way around.

Chapter 3 - Approach

The goal of this project is to find a way to see how modern technology can be used in helping a boardgame design process. To find a way to use modern technology for designing a game, it is of use to first look at what a normal game design process is. A simplified version of the process was made based on previous personal experience in game design. A visualization depicting this cycle can be seen in Figure 1.

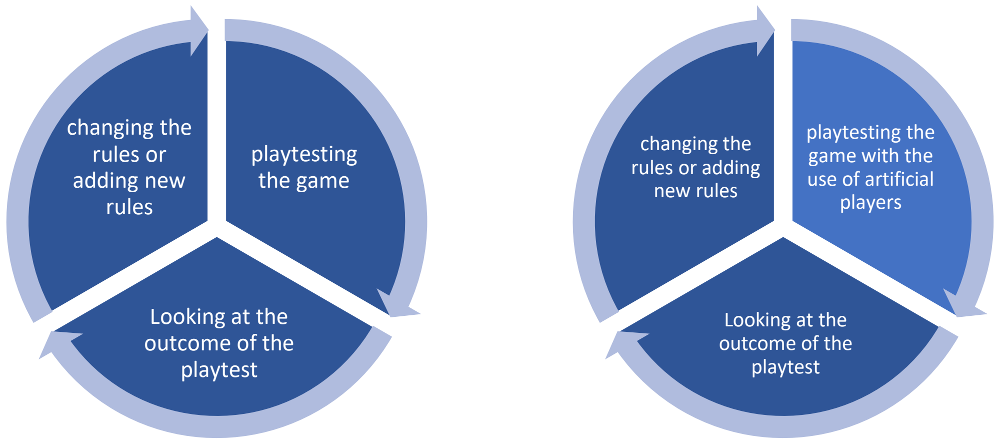

Figure 1: a normal game design cycle (left) and the improved game design cycle (right)

For this project, a look was taken into the second step of this game design cycle. The main concept here is that artificial players can replace or partially replace normal manual playtesting. For the tools required to do this a look will be taken at previous work. This cycle can be evaluated in two ways. For both evaluations, a game should be developed with this cycle. The first way to evaluate this cycle is from experience in using it as a game designer for developing a game. The second way to evaluate this cycle is to evaluate the resulting game with a human playtest. Ultimately, the game should be played and enjoyed by humans. Therefore, it is inevitable that in the end of designing the game a playtest using actual players is needed for proper evaluation. The evaluation of the game could give insight in the success of using this cycle for designing a game.

3.1 Ludii

Ludii is a General Game System developed by Browne et al. [11] It will function as the main tool used for developing and playtesting games in this project. A general game system is a system meant for playing a plethora of games. The Ludii General Game System in specifically was made for evaluation and designing a large variety of games. This includes card games, board games, dice games, and mathematical games. The Ludii system is funded by the European Research Council with its main goal to be used for Historical Game Research. The Ludii tool is used as both a means to universally document rulesets for historical games, but also to attempt to recover or complete missing rulesets for found boardgames.

```
(game "Tic-Tac-Toe"
    (players 2)
    (equipment {
        (board (square 3))
        (piece "Disc" P1)
        (piece "Cross" P2)
    })
    (rules
        (play (move Add (to (sites Empty))))
        (end ("Line3Win"))
    )
)
```

Figure 2: game description for the game: tic tac toe

To be able to support such a large variety of games, Ludii has created its own language and format for universally defining the rulesets of these games. The Ludii system uses .lud files to store a definition of a game. The language consists of the smallest possible units of game information called "ludemes". An example of this code can be seen in Figure 2.

AI agents within ludii

The Ludii system has multiple built-in AI controllers. The algorithm used for playtesting in this project is called Upper Confidence bounds applied to Trees (UCT), which is a variant of the Monte Carlo tree search (MCTS). MTCS is used for finding the optimal decision with a combination of tree search and random sampling. For some games other algorithms have better performances. However, the benefit of using UCT is that it performs relatively well on all games in general. The UCT algorithm therefore is the "standard" algorithm used in the Ludii system if no other algorithm is specifically mentioned in the meta-data of the ludeme file and is recommended by the developers. For the sake of playtesting and developing new games it would therefore also logically make sense to use this algorithm.

3.2 Creating a game

For creating a game that is playable within the Ludii system there are two parts that need to be defined for writing a ludeme: game equipment and game rules. The first part is the equipment of the game. The description of the equipment can be compared to all the parts and pieces that in the physical world are needed to play a game. The second part that needs to be defined are the rules of the game. The rules do not only describe how the game is played. They also describe how the game can be won or the when the game ends. For complete documentation of the Ludii language, the reader is referred to [13].

To see whether the playtesting using AI can help in developing games a new game will be developed. The Ludii system will be used during the development of the game to analyze different properties of the game that is in development. For the equipment of this game the board in Figure 3 will be used and 4 black and white game pieces. This set of equipment originates from an IEEE conference on games (CoG) conference where the ludii system was presented [14]. The set was given as an exercise to get attendants of the conference to engage with the Ludii system. This makes the equipment a suitable basis to start designing a new boardgame from. The equipment is present in the publicly released version of the Ludii application. In the application the ludeme which contains the equipment is called S.2 with the S standing for symbol.

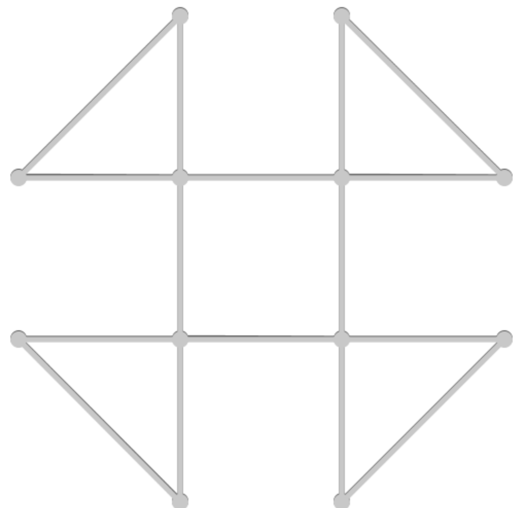

Figure 3: the shape of the board

The next step is to develop new rules for this game. During development new rules will be written in the Ludii language that go alongside with the equipment mentioned above. These rules will go through some changes during development based on the outcomes of the playtests using AI. The main concept is that changes are made to the ruleset according to outcomes of playtests and attributes found with the use of the AI players in the Ludii system. The main aspects that will be looked at with the Ludii system are the win rates of players with different strengths, and the decisiveness of the game. Based on the outcome of those parameters, new rules will or will not be added or rules will be adjusted.

Chapter 4 -Realization

The first iteration of the game rules can be found in Appendix I. The rules of this game must be written in the Ludii language for the system to be able to play the game. The rules of the game written in its ludemic form can be seen in Appendix II. After having written the rules in their ludemic form the game was ready to be played by artificial players. For playtesting two setups were used. In the first setup **Error! Reference source not found.**) both artificial players were set to play optimally using the Ludii AI, cf. Figure 3. In the second setupFigure 5 the Ludii AI would play against a player making random moves, cf. Figure 4. This is done to simulate a difference in skill between the two players.

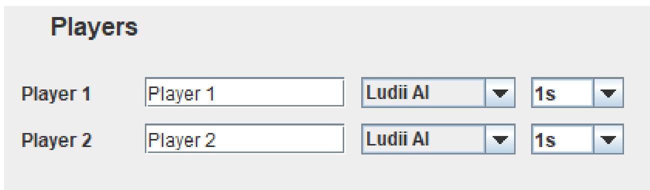

Figure 4: playtest setup A. UCT player versus UCT player.

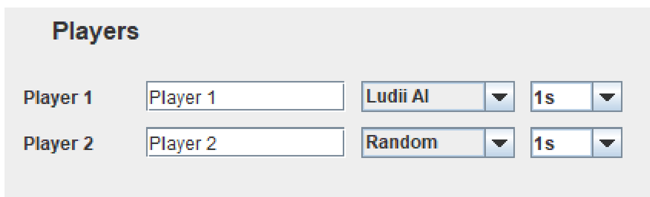

Figure 5: playtest setup B. UCT player versus random player.

After playtesting the original game with setup, A games would last indefinitely. Looking further into how the AI behaved it seemed that although the pieces kept moving the pieces would never leave their original corners. This is made visible in Figure 6, the red lines divide the board into 4 corners.

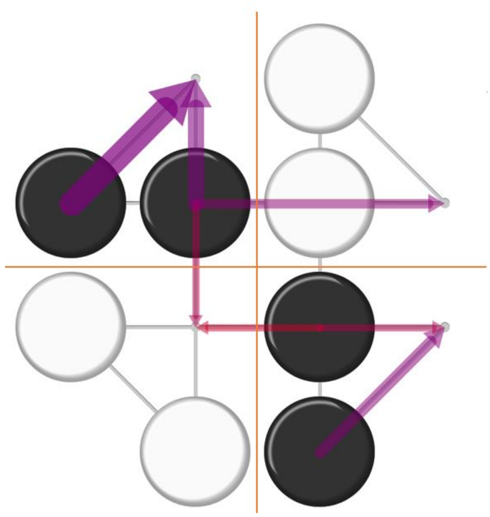

Figure 6: the board with AI visualized

To break this pattern different starting positions were tried out to not make the game last indefinitely and break the pattern. These starting positions can be seen in Figure 7. After testing again with setup, a game would still last indefinitely. However, the pieces now kept rotating around the board, making for a more interesting gameplay pattern. Since the win condition was never reached in setup A setup B was also used on this version. In setup B player 1 would eventually win all games. After this round of playtesting with AI a new rule was added where a player would gain an additional turn after jumping over an opponent's piece. The results of the playtests would remain the same for setup A and B.

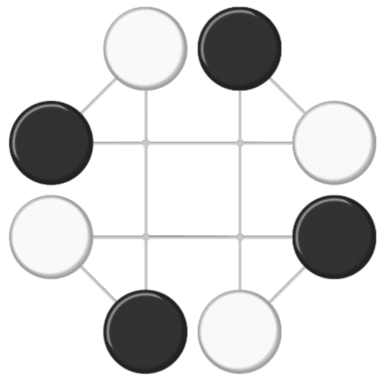

Figure 7: the new starting positions

To improve the game, it went through a couple of iterations, each with slightly adjusted rules. Eventually a game was made with the starting position that can be seen in Figure 7. Each turn a player can move one of their pieces, or a player can jump over an opponent's piece. The goal of the game is to make three in a row. The game now lasted 5 turns if both players play optimally. In setup B games would take around 17 turns. This game length was estimated by collecting data over 47606 trails. This was achieved by doing as many trials as possible within 30 seconds. This playtest was run on an intel i7 9^{th} gen processor and 16GB of RAM. This game length seemed well balanced for a game of this size. Therefore, it was decided to end the design cycle here.

Chapter 5 -User Evaluation

The user evaluation has two main goals for this project. The first goal is checking whether the use of artificial players for playtesting the games in the game design cycle succeeded in creating an enjoyable experience. The second goal of the evaluation is to see whether there is a connection between the perceived difficulty and the enjoyment of a players' experience. As this was suggested based on the findings of the literature review.

5.1 Approach / Experimental Setup

Artificial players were also used during the human playtest for multiple reasons. Using an AI opponent to play the game creates the same type of experience for all participants. As concluded in the background research, in combinatorial boardgames the skill of the opponent greatly influences the difficulty. Another benefit of using artificial players is the logistical advantage. Because AI was used playtest could be conducted individually.

The playtest was conducted with a group of 20 participants. Each participant was informed about the goals of the research with the use of an information brochure that can be found in appendix IV. Before continuing with the research, the participants were also asked to sign the consent form that can be found in appendix V. All participants were asked to play the game 3 times. In each first game the artificial opponent played first. In the second game the participant played first and in the third round the artificial player goes first again. This ultimately gave each participant 2 chances of winning the game since the artificial player always won the second game because it always played optimally.

topic	Statement
Mastery	I felt I was good at playing this game.
	I felt capable while playing the game.
	I felt a sense of mastery playing this game.
Challenge	The game was not too easy and not too hard to play.
	The game was challenging but not too challenging.
	The challenges in the game were at the right level of difficulty for me.
Enjoyment	I liked playing the game
	The game was entertaining
	I had a good time playing this game

Table 1: the statements used in the survey

After three rounds of playing the game participants were given a survey with 9 statements that could be answered on a Likert-scale from 1 to 7. There were 3 statements regarding the enjoyment of the game 3 regarding the sense of mastery whilst playing the game and 3 about the challenge of the game. The statements can be seen in Table 1. These statements were derived from the Player Experience Inventory (PXI)[1] benchmark. The PXI Benchmark is an evaluation tool specifically made for evaluating games. The original benchmark consists of 10 constructs of which enjoyment is not one. The

[1] *Link to PXI website: https://playerexperienceinventory.org/*

8 other constructs did however did not relate to the context of this project or were not beneficial. Another reason for using the PXI benchmark is that it includes clear instructions on how to conduct the playtests. Therefore, this would improve the quality of this research.

After these statements participants were also given two open questions to possibly give more insight about their experience with the game. One question was asking the participant about feedback regarding the difficulty of the game. The other questions were about any general feedback which could provide more insight to the outcomes of the playtest.

5.2 Results

The results of the Likert scale part of the survey can be found in Appendix VI. Each column contains the average value of the participants answer to the statements regarding the topic. Regarding the enjoyment of the game the overall average value of enjoyment was 4.95. Taking this value within the context of a scale from 1 to 7, where 4 is the most neutral option, this means that the experience was closer to being a neutral experience than being to a completely enjoyable experience. It also needs to be noted that purely from the enjoyment rating a perfect enjoyment was not to be expected. Enjoyment differs from person to person. Therefore, it can be concluded that overall people seemed to have enjoyed the game experience.

Enjoyment and perceived difficulty

The results of the playtests were analyzed by conducting a Spearman's correlation test. This test is most suitable for the data collected in the playtest since they are ordinal variables. The Spearman's correlation test also does not require assumption of normality. The correlation gives an indication of how strong the compared variables correlate to each other ranging from -1 to 1. With 0 being no correlation at all and -1 or 1 being complete correlation and complete negative correlation, respectively.

		enjoyment	challenge	mastery	perceiveddifficulty
enjoyment	Correlation Coefficient	1.000	.524	.543	.570
	Sig. (2-tailed)	.	.018	.013	.009
	N	20	20	20	20

Table 2: The correlation coefficients of enjoyment of the playtest results

The correlation coefficients can be seen in Table 2: The correlation coefficients of enjoyment of the playtest results. A full table of all correlations can be found in Appendix VII. Both challenge with a correlation coefficient of 0.542 and mastery with a correlation coefficient of 0.543 do not seem to correlate significantly with enjoyment. However, this value is also not low enough to prove that there is no correlation at all. Challenge and mastery were combined in equal weights of 0.5 to form the "perceived difficulty". This was not only done to possibly increase the accuracy of this variable since it now relied on more statements, but this was also done because challenge and mastery both contribute to how difficult a task is perceived. Which is the variable that is most related to the goal of the playtest. Furthermore, the combination of these two variables is supported since they correlate very strongly with each other with a correlation coefficient of 0.822.

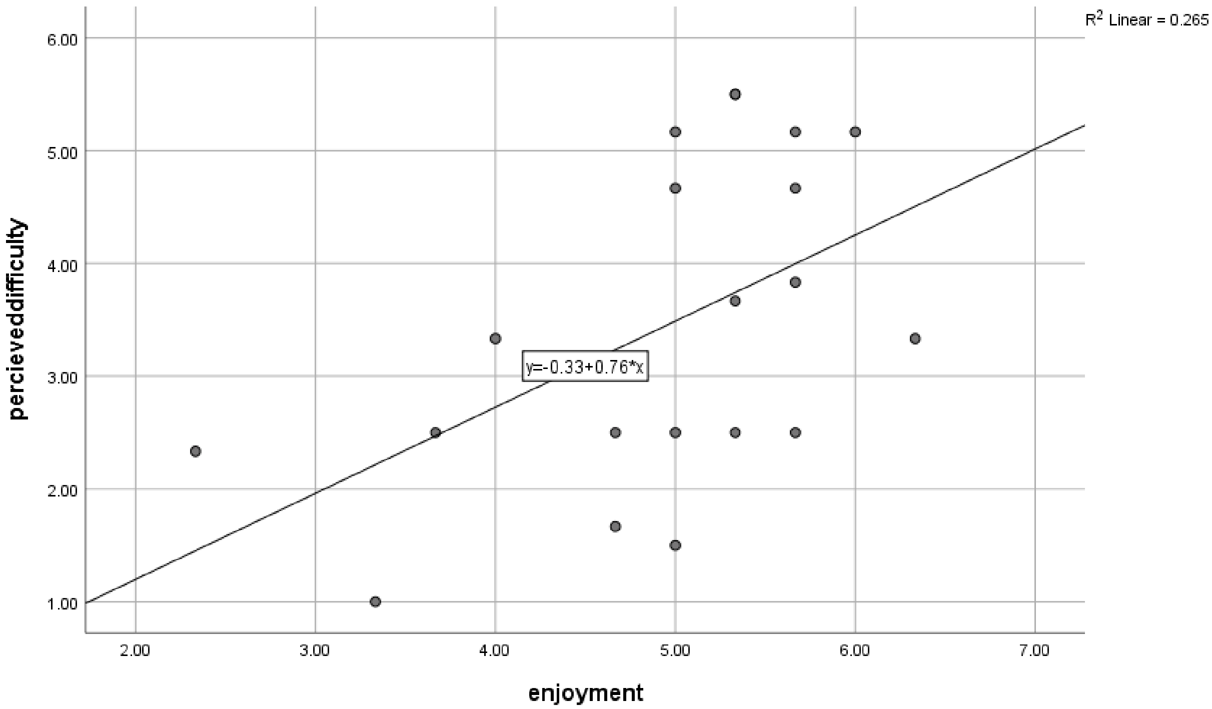

Figure 8: The perceived difficulty set out to the enjoyment of participants

The perceived difficulty is set out against the enjoyment in Figure 8. The correlation coefficient of the two variables is 0.570. This indicates that they are, although not significant, closer to correlate to each other than for there to be no correlation at all.

Gameplay

During playtesting participants would sometimes end up in an endless loop. The participants that got stuck in this loop were able to see which moves would directly result in the opponent winning the game. An endless loop was not expected based on the playtest using artificial players. This was caused because of the difference in human behavior and the behavior of the AI.

Chapter 6 -Discussion

Game design principles

Throughout the design process when using the cycle to design a new game, the focus was entirely on the rules of the game. However, taking one step back and again looking at regular game design principles could give further insight in the results of this project.

Puzzle or game

Although an enjoyable experience was created with the use of improved game design cycle, ultimately the game turned out to be more a puzzle than a game. This arguably is the case for most if not all combinatorial boardgames. Most combinatorial games have an optimal strategy. This holds for the game developed in this thesis as well. This optimal strategy can be seen as a solution, turning the game into a puzzle.

Being a combinatorial game does not inherently make the game a bad game. Chess is an example of a combinatorial game that still is extremely popular. This could be because there has not been found an “optimal solution” to this game. Thus, arguably making the game one of the best tests of skill of both players. And therefore, enjoyable to a wide variety of players. The same could be said for this game. As long as the solution to this game has not been found by the player, it makes for an enjoyable experience.

Elemental tetrad

A conventional boardgame also exists of more aspects than just the rules. A comparison can be made to the elemental tetrad by Jesse Schell which can also be seen in Figure 9 [15]. In his book he distinguishes the 4 main elements of a game: aesthetics, mechanics, story, and technology. The focus of this thesis was only on the rules or “mechanics” of the game. All other elements are present in the designed boardgame but have not been given any changes within this project.

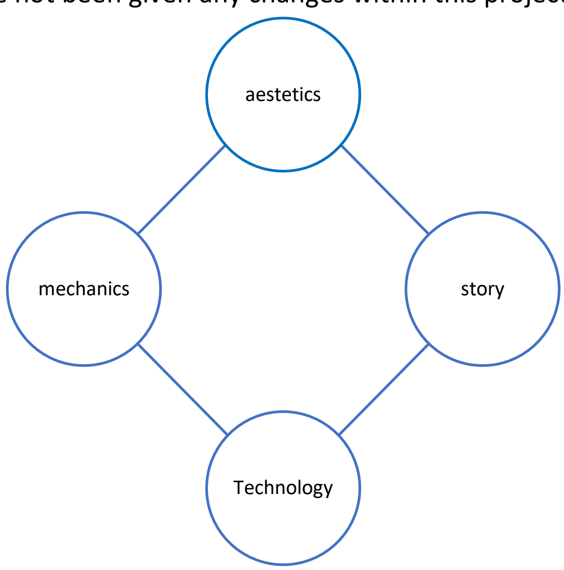

Figure 9: the elemental tetrad by Jesse Schell [15]

These other aspects might also have contributed to how much people enjoyed the game. However, these influences were kept as minimal as possible. The players were not given any story elements other than the goal of beating your opponent. The aesthetics of the game were made to be as simplified as possible. With black and white pieces on a white background. And the technology, in this case the Ludii system on a laptop was the same for all participants. Even when reducing these aspects to the bare minimum it still needs to be taken into consideration that they might have had an influence on the enjoyment of the game experience.

Human vs AI playtest

Playtesting with AI immediately gives insight into the exact properties of a game. How difficult a game is can be partially predicted based on the outcomes of playtests using artificial players. With difficulty here referring to the amount of possible moves a player has and the duration of the game when played optimally. This prediction, however, is different from the perceived difficulty from a player. Playtesting with humans showed how difficult the game is really experienced as. The statistical parts obtained from playtesting with artificial players do not seem to be translatable directly to the difficulty experienced by the player.

This means that the difficulty a player experiences depends on more factors than the ones that can be measured or observed when playtesting using AI. More factors influencing the experience of a player ties in with the fundamental game elements named the “elemental tetrad” (Figure 9) by Jesse Schell [15]. The part of the elemental tetrad that is being assessed when playing with artificial player is only the mechanics of the game. Changing the other elements change the experience of the game. This in turn could change the perceived difficulty of a game, which in its own turn affects the enjoyment of a game. This means that artificial playtest can only be used for predicting part of the experience that a game offers. Nonetheless, it does this in a vastly more efficient manner than playing with actual players.

Chapter 7 - Conclusion

The goal of this thesis was to find how modern technology can be used to automatically generate and evaluate (combinatorial) boardgames.

SQ1: What factors could be used to determine or predict the quality of a boardgame?

For the scope of this thesis, it was chosen that a good quality game should be one that is enjoyable. Based on the literature reviewed it was hypothesized that enjoyment mostly comes from how difficult or challenging someone perceives a game. Correlation between *perceived difficulty* and *enjoyment* lacked significance. It also lacked the significance to disprove any correlation. This means that perceived difficulty could still be one of the main predictors of whether someone will enjoy a game or not. There seem to be predictors of what makes games enjoyable, and more experiments are necessary to refute the hypothesis

SQ2: How can modern technology be used to automatically generate any (combinatorial) boardgames?

Modern technology can effectively be used as a tool to guide in developing combinatorial boardgames. The way modern technology can help in developing games reviewed in this thesis is the use of artificial players for playtesting. Although artificial players do not give the same insight in gameplay behavior as playtests with actual human players, the use of artificial players could reduce part of the playtesting part of a boardgame design cycle.

How can modern technology be used to automatically generate and evaluate (combinatorial) boardgames?

Modern technology can be an effective tool in guiding game design. Although complete automation of developing and evaluating combinatorial boardgames was not achieved in this thesis, steps were made in both directions. Playtesting games can be partially automated with the use of artificial players, and difficulty can potentially be used to predict the quality of a game.

Chapter 8 - Future Work

The game design cycle

In this thesis the improved game design cycle using artificial players for playtesting was introduced. The first use of this new process led to an enjoyable game experience. However, there is still much left to be explored. In this thesis the cycle is reviewed by evaluating the resulting game. To discover whether this cycle is truly beneficial in developing games, more research should be done on the use of this new approach rather than the outcomes of the cycle. More experienced game or boardgame designers could be interviewed or asked to use this cycle to see whether it is effective in practice.

Effects on creative process

Designing new boardgames is somewhat of an artistic profession that requires imagination. Especially coming up with new rules for a game can be a very difficult task. In this thesis the Ludii system was used as a tool for doing the playtests with artificial players. To use the system the game that is to be tested needs to be written in its ludemic form. Because the game needs to be written in the ludii language to get it in its ludemic form, the developer of the boardgame is limited by their understanding of the ludii language. This could potentially reduce the creativity of the designer. If simpler rules or rules that are more easily implementable are chosen solely for this reason. Because of this further research should be done into the effects of using a potentially limiting language in the design process. Although this could potentially be solved by separating the design process completely from the implementation of the game within the ludii system, it might still subconsciously influence the decision-making process of the game designer using the cycle.

Perceived difficulty

If there is a correlation between perceived difficulty and enjoyment, more research should be done to what aspect of the rules affect a player's perceived difficulty. This thesis did not focus too heavily on what exactly makes games perceived as more difficult. The factors that make games inherently more difficult such as complexity and number of rules might be completely different from the factors that alter one's perceived difficulty. There are more aspects to a game than just the rules that determine a player's experience. Only when the effect of changing a rule on a player's perceived difficulty is researched can this information be used to accurately predict the enjoyment and therefore part of the quality of a game.

This thesis was not able to provide significant proof of the correlation between perceived difficulty and enjoyment. Nonetheless, the connection between perceived difficulty or challenge and enjoyment was already supported by the flow theory [7]. Flow theory considers many more experiences or activities than just gaming. More research could be done about the specific connection between perceived difficulty and enjoyment in playing boardgames.

References

[1] arizton, “Board Games Market - Global Outlook and Forecast 2021-2026,” vol. 3. arizton, Dec. 2020.

[2] E. Bakhanova, J. A. Garcia, W. L. Raffe, and A. Voinov, “Targeting social learning and engagement: What serious games and gamification can offer to participatory modeling,” *Environmental Modelling & Software*, vol. 134, p. 104846, 2020, doi: https://doi.org/10.1016/j.envsoft.2020.104846.

[3] A. Z. Abbasi, D. H. Ting, H. Hlavacs, L. V. Costa, and A. I. Veloso, “An empirical validation of consumer video game engagement: A playful-consumption experience approach,” *Entertainment Computing*, vol. 29, pp. 43–55, 2019, doi: https://doi.org/10.1016/j.entcom.2018.12.002.

[4] J. Banyte and A. Gadeikiene, “The Effect of Consumer Motivation to Play Games on Video Game-playing Engagement,” *Procedia Economics and Finance*, vol. 26, pp. 505–514, 2015, doi: https://doi.org/10.1016/S2212-5671(15)00880-1.

[5] E. A. Boyle, T. M. Connolly, T. Hainey, and J. M. Boyle, “Engagement in digital entertainment games: A systematic review,” *Computers in Human Behavior*, vol. 28, no. 3, pp. 771–780, 2012, doi: https://doi.org/10.1016/j.chb.2011.11.020.

[6] J. H. Brockmyer, C. M. Fox, K. A. Curtiss, E. McBroom, K. M. Burkhart, and J. N. Pidruzny, “The development of the Game Engagement Questionnaire: A measure of engagement in video game-playing,” *Journal of Experimental Social Psychology*, vol. 45, no. 4, pp. 624–634, Jul. 2009, doi: 10.1016/J.JESP.2009.02.016.

[7] M. Nakamura Jeanne and Csikszentmihalyi, “The Concept of Flow,” in *Flow and the Foundations of Positive Psychology: The Collected Works of Mihaly Csikszentmihalyi*, Dordrecht: Springer Netherlands, 2014, pp. 239–263. doi: 10.1007/978-94-017-9088-8_16.

[8] D. A. Laffan, J. Greaney, H. Barton, and L. K. Kaye, “The relationships between the structural video game characteristics, video game engagement and happiness among individuals who play video games,” *Computers in Human Behavior*, vol. 65, pp. 544–549, 2016, doi: https://doi.org/10.1016/j.chb.2016.09.004.

[9] M. Pienimäki, M. Kinnula, and N. Iivari, “Finding fun in non-formal technology education,” *International Journal of Child-Computer Interaction*, vol. 29, p. 100283, 2021, doi: https://doi.org/10.1016/j.ijcci.2021.100283.

[10] I. Kniestedt, I. Lefter, S. Lukosch, and F. M. Brazier, “Re-framing engagement for applied games: A conceptual framework,” *Entertainment Computing*, vol. 41, p. 100475, 2022, doi: https://doi.org/10.1016/j.entcom.2021.100475.

[11] Y. B. Kafai, “Constructionist visions: Hard fun with serious games,” *International Journal of Child-Computer Interaction*, vol. 18, pp. 19–21, 2018, doi: https://doi.org/10.1016/j.ijcci.2018.04.002.

[12] C. Browne and F. Maire, “Evolutionary Game Design,” *IEEE Transactions on Computational Intelligence and AI in Games*, vol. 2, no. 1, pp. 1–16, 2010, doi: 10.1109/TCIAIG.2010.2041928.

[13] Browne Cameron, Soemers Dennis, Piette Eric, Stephenson Matthew, and Crist Walter, "Ludii Language Reference," Maastricht, Jun. 2022.

[14] M. Stephenson and C. Browne, "Designing, Playing and Testing Games with Ludii," Aug. 26, 2020. https://www.youtube.com/watch?v=pTkO8h8RBBI&ab_channel=Ludii (accessed May 17, 2022).

[15] Jesse Schell, *The Art of Game Design A Book of Lenses*, 3rd ed. CRC Press, 2020.

Appendix I – Initial game description

First iteration of game equipment list and rules

Equipment list:

1x board

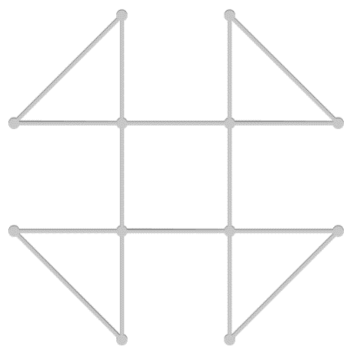

Figure playing board

4x black playing pieces

4x white playing pieces

Rules:

Players start with their pieces in the opposing corners of the board.

(if 2 white pieces are on the top left, the other two are in the bottom right)

Players can jump over each other's pieces and their own.

The goal of the game is to get four in a row.

Appendix II - initial game ludeme

Note: For the shape and equipment of the board the description has been re-used from the description of the before mentioned S.2 game.

```
(define "HopMan"
    (move
        Hop
        (from #1)
        (directions {FR FL BL BR Forward Backward Leftward Rightward})
        (between
            if:(is Enemy (who at:(between)))
        )
        (to if:(is Empty (to)))
        #2
    )
)

(define "StepMan"
    (move
        Step
        (to if:(is Empty (to)))
    )
)

(define "IfLine3MoveAgain"
    (then
        (if
            (is Line 3)
            (moveAgain)
        )
    )
)

//----------------------------------------------------------------------
----------

(game "Symbol S.2"
    (players 2)

    (equipment {
        (board
            (graph
                vertices:{ {1 0} {2 0} {0 1} {1 1} {2 1} {3 1} {0 2}
{1 2} {2 2} {3 2} {1 3} {2 3}}
                edges:{ {0 2} {0 3} {3 2} {3 4} {1 4} {4 5} {1 5} {3
7} {4 8} {6 7} {7 8} {8 9} {6 10} {11 9} {10 7} {11 8}}
            )
```

```
            use:Vertex
        )
        (hand Each)
        (piece "Marker" Each
            (or
                "StepMan"
                "HopMan"
            )
        )
    })
    (rules
        (start
            {
                (place "Marker1" {"B1" "A2" "C4" "D3"})
                (place "Marker2" {"A3" "B4" "C1" "D2"})
            }
        )

        phases:{
        (phase "Movement"
            (play
                (forEach Piece)
            )
        )
        }
        (end
            (if
                (is Line 4)
                (result Mover Win)
            )
        )
    )
)
```

Appendix III – Final Game

```
(define "HopMan"
    (move
        Hop
        (from #1)
        (directions {FR FL BL BR Forward Backward Leftward Rightward})
        (between
            if:(is Enemy (who at:(between)))
        )
        (to if:(is Empty (to)))
        #2
    )
)

(define "StepMan"
    (move
        Step
        (to if:(is Empty (to)))
    )
)

(define "IfLine3MoveAgain"
    (then
        (if
            (is Line 3)
            (moveAgain)
        )
    )
)

//----------------------------------------------------------------------
----------

(game "Symbol S.2"
    (players 2)

    (equipment {
        (board
            (graph
                vertices:{ {1 0} {2 0} {0 1} {1 1} {2 1} {3 1} {0 2}
{1 2} {2 2} {3 2} {1 3} {2 3}}
                edges:{ {0 2} {0 3} {3 2} {3 4} {1 4} {4 5} {1 5} {3
7} {4 8} {6 7} {7 8} {8 9} {6 10} {11 9} {10 7} {11 8}}
            )
            use:Vertex
        )
        (hand Each)
```

```
        (piece "Marker" Each
            (or
                "StepMan"
                "HopMan"
            )
        )
    })
    (rules
        (start
            {
                (place "Marker1" {"A2" "B4" "C1" "D3"})
                (place "Marker2" {"B1" "A3" "C4" "D2"})
            }
        )

        phases:{
        (phase "Movement"
            (play
                (forEach Piece)
            )
        )
        }
        (end
            (if
                (is Line 3)
                (result Mover Win)
            )
        )
    )
)
```

Appendix IV – Information Brochure

Below is the information brochure handed out to all participants to inform them about the necessary information regarding the playtest and research.

Don’t rate the player rate the game information brochure

Context

Designing high quality boardgames costs a lot of time. The goal of this study is to find how modern technology can help in the development of new boardgames. The concept that will be tested is the use of certain variables which are obtained by simulating the boardgame being played with the use of AI. Such as game duration, complexity etc. To see whether using these variables can help designing new boardgames, the game will be play tested.

Procedure

To participate you need to be: i) at least 18 years old ii) have the capacity to quickly understand new boardgame rules. iii) have experience playing other boardgames

The playtest and questionnaire will take a maximum of 45 minutes.

In the first part you will be informed about the rules of the boardgame. You will then be asked to play the boardgame against an AI opponent. The game will be played on a laptop provided to you by me. The play test will be done against an AI opponent as to create equal experiences for all participants. A screenshot of the application that will be used for this can be seen below. While you are playing this game the duration will be measured with a timer. After finishing the game, you will be asked to fill out a survey with questions regarding the boardgame.

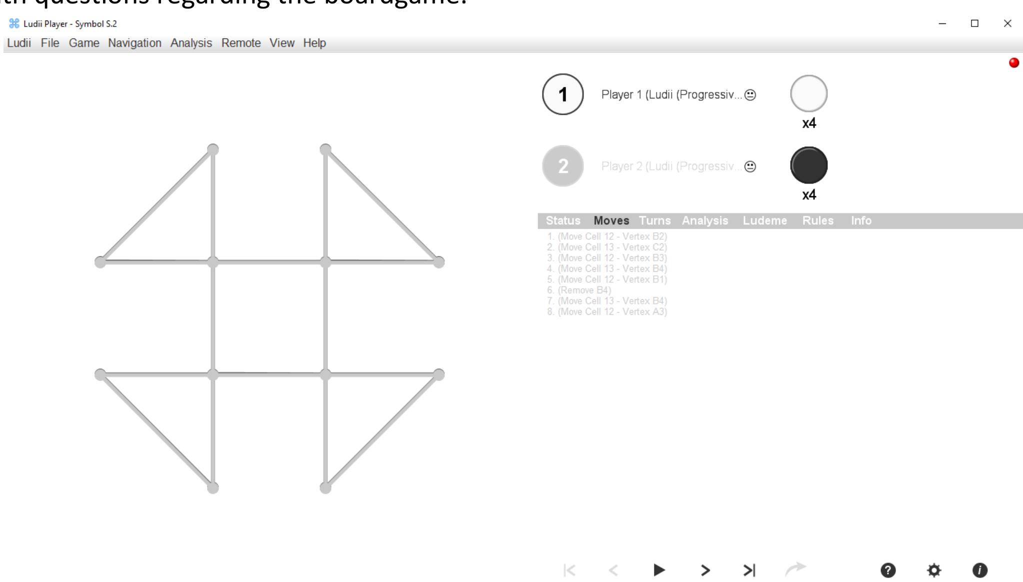

Figure 1: a screenshot of the application that will be used during the playtest

Game rules

NOTE: *as the game is still in development these rules are subject to last minute changes*

You play either with the black or white pieces. Both players start with 2 pieces in each of the opposing corners. The goal of the game is to get 4 in a row. Each turn you can move a piece one place across the board. A piece can also hop over an opponent's piece. Hopping over an opponent's piece grants you an additional turn.

Participation

- As a participant, you will participate voluntarily in this playtest and questionnaire. You have the right to decline to take part and withdraw from the research once participation has begun, without any negative consequences, and without providing any explanation.
- The information gathered will be protected and anonymized. Also, any personally identifiable information will be removed from the gathered data after the playtest.

What data will be obtained

The data that will be obtained are the duration and outcome (win/draw/loss) of the playtest and the outcomes of the questionnaire. All data will be stored anonymously. The answers to the questionnaire may be interesting to be quoted in the final thesis. Giving approval for this is completely optional.

If you have questions or want more information regarding the research, you can contact:
b.m.vandeweerd@student.utwente.nl

+31 6 31088291

Or my supervisor:

m.gerhold@utwente.nl

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science:

ethicscommittee-CIS@utwente.nl

Appendix V - Consent Form

Below is the consent form that was given to all participants after being given the information about the playtest prior to them taking part in the actual playtest.

Consent Form for: Don’t rate the player rate the game

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [DD/MM/YYYY], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves playtesting a boardgame of which the duration is being recorded with a timer followed up by filling in a digital survey of which the data is collected.	○	○
Use of the information in the study		
I understand that information I provide will be used for evaluating the quality of a newly developed boardgame, and in turn to evaluate the effectives of using modern technology in boardgame design.	○	○
I understand that personal information collected about me that can identify me, such as my name will not be shared beyond the study team.	○	○
[OPTIONAL] I agree that my information can be quoted anonymously in research outputs	○	○

_______________________ _______________________ _________ Name of participant [printed]

Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

__________________________ ____________________ _________

Researcher name [printed] Signature Date

If you have questions or want more information regarding the research, you can contact:

b.m.vandeweerd@student.utwente.nl +31 6 31088291

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer

UNIVERSITY OF TWENTE.

Science: ethicscommittee-CIS@utwente.nl

Appendix VI -playtest results

enjoyment	challenge	mastery	percieved difficulty
5.00	5.67	3.67	4.67
3.33	1.00	1.00	1.00
4.00	4.00	2.67	3.33
5.00	4.00	1.00	2.50
6.33	3.33	3.33	3.33
5.33	2.67	2.33	2.50
4.67	2.00	1.33	1.67
5.00	2.00	1.00	1.50
4.67	2.33	2.67	2.50
2.33	2.67	2.00	2.33
5.33	5.00	6.00	5.50
5.33	5.33	5.67	5.50
5.67	3.00	2.00	2.50
6.00	5.00	5.33	5.17
5.67	4.67	3.00	3.83
5.00	5.00	5.33	5.17
5.67	5.67	4.67	5.17
5.33	4.67	2.67	3.67
3.67	3.00	2.00	2.50
5.67	5.33	4.00	4.67

Appendix VII -Correlation coefficients

Correlations

			enjoyment	challenge	mastery	perceiveddifficulty
Spearman's rho	enjoyment	Correlation Coefficient	1.000	.524*	.543*	.570**
		Sig. (2-tailed)	.	.018	.013	.009
		N	20	20	20	20
	challenge	Correlation Coefficient	.524*	1.000	.822**	.922**
		Sig. (2-tailed)	.018	.	.000	.000
		N	20	20	20	20
	mastery	Correlation Coefficient	.543*	.822**	1.000	.957**
		Sig. (2-tailed)	.013	.000	.	.000
		N	20	20	20	20
	perceiveddifficulty	Correlation Coefficient	.570**	.922**	.957**	1.000
		Sig. (2-tailed)	.009	.000	.000	.
		N	20	20	20	20

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).