# Team 13

# Design Showcase 2 Report

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## 0.0 Executive Summary

This report summarizes the design process following the first design showcase report for BME 161 at the University of Waterloo. The situation of concern remains to adapt the *Settlers of Catan* board game to be more accessible to those experiencing tremors resulting from conditions such as Parkinson's disease and Multiple Sclerosis. The product should be intuitive to use and allow players to participate in the game flow without loss of speed or enjoyment. The re-empathize, design solution, defining specifications, prototype planning, engineering analysis, and testing phases are covered.

In the re-empathize phase, a critique analysis was conducted, with feedback from peers and upper years. The two key takeaway points from the critique received were to better define exactly what stages of Parkinson's the designed solution would aid, as well as to better understand specifically where in the design magnets should be used. This led to the conclusion that the capabilities of the design could enhance gameplay for those with up to stage 3 Parkinson's disease as initially planned, and that magnets would only be used to connect tiles so as to reduce potential magnetic interference with other game elements.

In the design solution phase, the SWOT analysis was re-inspected to determine the feasibility, cost, functionality, and user experience of the design concept as compared to the other options. Then, means for the core functions of the solution morph chart were chosen for the best balance of feasibility, effectiveness, and preservation of the original gameplay experience. After the above, the chosen design solution was decided to be a redesigned Catan board that secures gameplay pieces by placing them in holes in the board. As well, to reduce the size of the board, ports are reimagined as triangular edge-tiles and all tiles are connected by magnets, removing the need for the original blue frame while keeping the overall structure familiar.

The prototype planning phase discusses the steps taken prior to prototyping. This includes the consideration of all of the various components of Catan: the pieces and movements involved in gameplay, and how those aspects could possibly affect players with tremors. These considerations were important when developing a realistic solution that would actually be beneficial for players with tremors. To measure tangible results of the impact of the design on players with tremors, a test was developed that involved measuring the lateral force required to move a piece. The pieces tested include settlements, roads, tiles, and cities.

The engineering analysis aims to find how much force is necessary to separate a single tile from a cluster of three tiles. The hexagonal shape of tiles means the necessary pulling force in this scenario must overcome the strength of four magnets at an angle. Additionally, to prevent slipping, a minimum amount of gripping force on the tiles must be met for friction to overcome the pulling force. These values were calculated using an approximation of the magnetic field density of the magnets and the coefficient of friction between skin and PLA material. It was found that the forces required fell between the target and threshold values, meaning the design is acceptable in regard to the force needed to separate tiles.

The redesigned Catan pieces were developed to improve stability for players with hand tremors while preserving the game's look and rules. A p-diagram identified inputs, noise factors, quality measures (force to detach and to insert/remove pieces), targets, experiments, and controllable parameters, principally

magnet configuration and mechanical geometry (slot dimensions, edge radius, piece weight, thickness and size). Controlled lab tests used a handheld force gauge (100 Hz, 0 - 50 N range, ±0.25 N) to measure lateral force required to displace roads, settlements, cities and the robber; mechanical parameters varied included slot depth, piece size/thickness/weight and angle of applied force while magnet properties were held constant. Results show the redesigned pieces require greater lateral force to displace, especially with increased slot depth, meeting the primary stability objective, though settlements become vulnerable to being displaced when force is applied high above the base. Key recommendations are reducing settlement height while retaining base geometry to ensure stability for all pieces.

The initial prototype testing confirmed that the magnetic tile connection and the indents for the various pieces do increase stability, which directly addresses the primary user need identified in the initial Empathize phase. The stability in the Catan game components is central to the design, as it provides an inclusive and engaging playing experience for all players with tremors by facilitating independence and dignity throughout the game.

The key features of the final design are the stability of the connecting tiles, the pieces that are inserted onto the tiles, and the ergonomics of each component. The overall board stability is a result of the magnetic connection mechanism between the tiles, which eliminates the need for the ocean frame in the original game. This reduces the overall surface area of the game, which makes the board more reachable and accessible. The stability of individual pieces is ensured by the indents on top of and between the tiles, which reduce the accidental movement of pieces throughout the game and clearly indicate to players where each piece should be placed. The pieces and tiles were also designed to be larger, slightly heavier, and with an increased amount of edges/chamfers to make them better for individuals with limited dexterity to grip onto.

The next steps in the design process would be re-entering the Empathize phase to focus on the balance between the two competing measures: the force required to accidentally detach pieces (which should be increased to reduce accidental piece movement) and the force required to insert or remove pieces from the indents (which should be decreased to facilitate straightforward placement and removal). This involves using the data collected from testing to continue to reiterate the design. The Empahtize phase would focus on user satisfaction to ensure that not only are the pieces stable, but they are also intuitive to use and enhance the Catan playing experience for users with tremors. This would be measured through qualitative tests that collect feedback on perceived effort required to use the pieces for the duration of the game to determine whether the increased size and weight of the pieces do not make the handling of the pieces too difficult for players with tremors. These adjustments ensure that the design is not only usable but also enjoyable

## 1.0 Re-Empathize Phase

### 1.1 Outputs from first design iteration

The situation impact statement was to design an adaptive *Settlers of Catan* system for players with hand tremors from neurological or motor-control disorders that enables rolling dice, picking up and placing pieces, managing cards, and maintaining board order with ease and precision. The product should be intuitive to use and allow players to participate in the game flow without loss of speed or enjoyment.

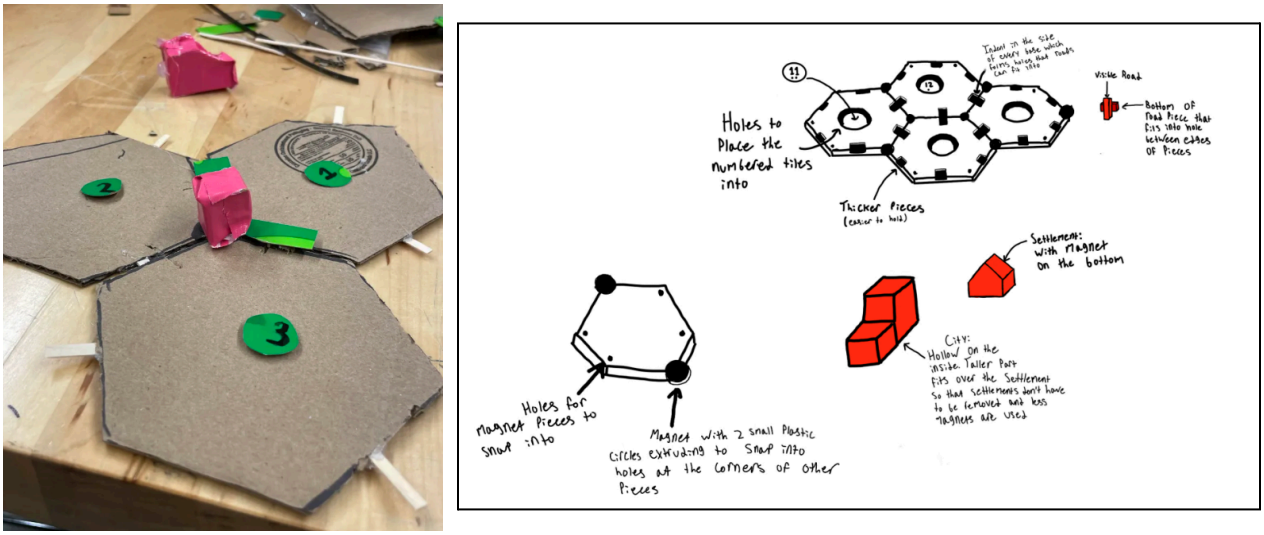


*Fig. 1.* Magic LFP and initial concept sketches

The decided upon solution primarily involved stabilizing the non-fixed pieces on the original Catan board. To do this, indents in the tile pieces are to be added for roads, settlements, cities, and number tokens. These pieces would then have an extended base that is thinner than the main piece, allowing it to slot into the tile and resist toppling over as easily.

Another aspect of the proposed solution was to make the overall board smaller. To achieve this without reducing the playing space, the large water tiles in the original board were designed to be reduced to just triangles that fit in between the edges of resource tiles. This effectively achieves two goals: reducing the overall board size while increasing the playing space.

### 1.2 Critical reflection of first design iteration

#### 1.2.1 Critique Analysis

The goal of the redesigned Catan tiles and pieces was to ensure that people with tremors could enjoy the game without knocking over pieces and disturbing the board setup. During the mentorship session and gallery walk, the design was well-received in terms of feasibility and outcome, but several concerns were raised about its capabilities. One of the most common questions was how players with severe tremors would place roads and houses into the small slot designs. This concern challenged the original design by showing that, although the solution stabilized pieces, it did not fully address the fine-motor limitations experienced by players with more severe tremors.

The design initially proposed magnets throughout the piece's slots to account for tremors and correct placement. Magnets were chosen to help compensate for pieces being slightly misaligned, but feedback revealed that excessive magnets could cause unintended repulsion and make storage more difficult. This also highlighted that certain magnets offered little usability benefit, prompting the team to remove them from areas where they created more issues than solutions. Concerns were also raised about resource card trading, which was not included in the prototype; the team acknowledges that card management remains an unresolved accessibility challenge to be addressed in the next iteration.

In summary, the key takeaways from the mentorship and design showcase were:

- Identify which stages of Parkinson's and similar tremor-causing disabilities the design should target.
- Use magnets intentionally to ensure proper piece placement.
- Avoid using too many magnets to prevent repulsion and storage challenges.
- Use larger, tactile pieces to improve grip and placement while keeping the board comfortably within reach.

After receiving this feedback, the team focused on determining where magnets would be most effective. Criteria included proximity to other magnets, movement during gameplay, and magnet strength. As a result, magnets were used only to connect tiles, since magnets in the piece slots risked pulling pieces into the wrong positions. Magnet placement in piece slots remains a future consideration pending further testing. Magnets were not used for the thief or number tiles, as the redesigned thief already stayed in place, and number tiles do not need repositioning during gameplay. The team also explored alternative non-magnetic mechanisms but found magnets to provide the most efficient gameplay when used correctly.

Further research indicated the design would enhance gameplay for individuals with up to stage 3 Parkinson's disease; those with higher tremor severity would still face challenges. Stage 3 was identified as the target group of the design because feedback showed that beyond this level, the tremors would become too strong to address with magnets and new piece designs. The critique transformed the design into a solution that is more efficient, intuitive, and aligned with the identified requirements and constraints.

### 1.2.2 Content Reflection

Throughout the SOC process, the tasks and tools of the stakeholders were clear. This included tools like the Catan pieces and tiles, and the tasks for interacting with players, picking up and placing pieces, game setup, card trading and more. Identifying these made it clear that the focus of the design for players with tremors should be physical aspects of the board game, specifically picking up and placing down pieces. After identifying the tasks and tools, it became clear which environments were relevant, but they were ultimately deprioritized because typical Catan gameplay occurs in stable indoor settings where environmental factors have minimal impact on tremor-related challengesHowever, it was uncertain how this would impact the design and how it could be included in the ideation and reiteration process, as it did not seem important to the problem space created. The primary stakeholders, being Catan players with tremors and caregivers/teachers that may play with them, were clear and defined the design process; this ensured the focus of the design did not change the game for anyone. However, it was harder to choose and empathize with the indirect stakeholders, like Catan Studios and the board-game community. There was a consensus that the prototype would likely be more expensive to produce; however, it would benefit both players with and without tremors during gameplay by keeping pieces/tiles in place. As a result, it became difficult to consider indirect stakeholders. The values identified were easy to maintain and directly related to requirements that defined the project. The values included maintaining the essence of the game of Catan, board reachability, the dignity of all players, and ensuring that the game pieces were intuitive to use. Overall, the elements of the SOC were understood, and it was clear how these elements should be defined in the problem space chosen. However, the team was uncertain of how to implement all aspects of the SOC through each stage of the design process and often feared overlooking important aspects that the final prototype needed to embody. As some aspects, including; environment of direct stakeholders, as it was deprioritized, and the values, tasks, tools, and environments of the indirect stakeholders

After reflecting on the SOC, it is important to specify the primary stakeholder by determining a range of tremors that the design aims to resolve. To consider the embodiment of the stakeholder values, the design should be more inclusive in order to maintain the dignity of all players; this can be done by considering design solutions for card trading during gameplay. Additionally, the solution should reduce player frustrations from pieces not staying in place and ensure that the design feels practical, not clinical.

The next steps correlate to what was identified as key takeaways from the critique reflection, as they are tied to many elements of the SOC. In addition, it is important to improve the graspability based on requirement R.1 (see Appendix A) for the roads, cities and settlements by focusing on size and texture. To further embody the requirement and value of easy assembly and storage, there must be a redirected focus on how magnets will be incorporated in the next prototype and how this may affect other aspects of the game indirectly. The team should reiterate and make a prototype to test the effects of magnets, the reachability of the board, and the difficulty/force required to assemble the board and place pieces in slots throughout gameplay.

## 2.0 Design Solution – Final Concept

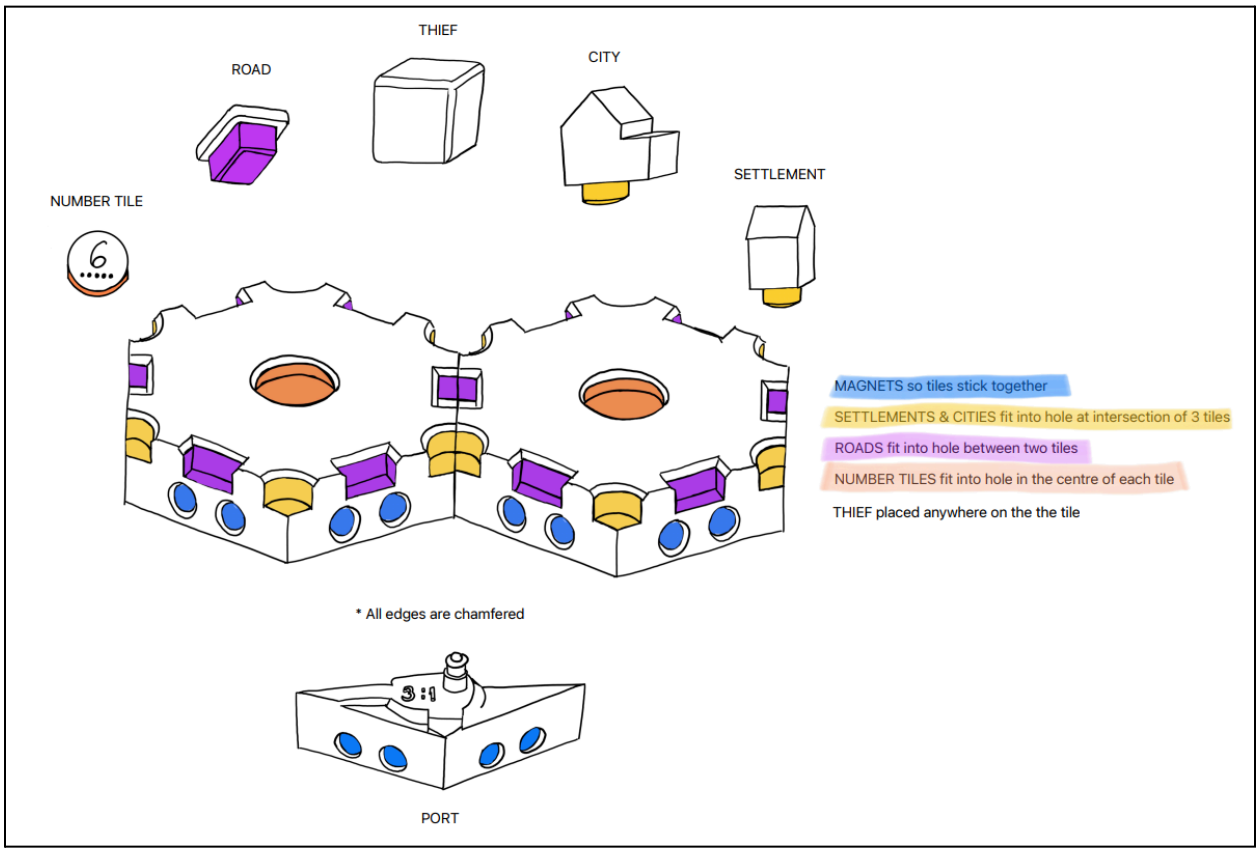


*Fig. 2.* Concept sketch of design solution

### 2.1 Description

The chosen design solution is a redesigned Catan board that secures gameplay pieces by placing them in indents in the board. As well, to reduce the size of the board, ports are reimagined as triangular edge-tiles and all tiles are connected by magnets, removing the need for the original blue frame. This solution was chosen because it best balanced feasibility, cost, functionality, and user experience when evaluated against the SWOT analysis found in Appendix B.

Several strengths from the SWOT analysis directly supported this decision. Firstly, it was found that this design is highly feasible and simple to make. This solution was compared to three others, which all used electronics, sensors, or mechanical devices. Due to this, the other options were much more expensive as a solution and much more difficult to prototype. As well, this solution offers stable gameplay and minimizes accidental movement, which aligns with the core need of the solution to improve piece stability without changing gameplay. Compared to the alternative solutions, which change the look of the gameboard by adding a claw machine, an app, or light-up elements, this design solution best fits the core need. Finally, the chosen solution fulfilled another core need of being portable, easily packed away in the game box, and very user-friendly and intuitive to use.

The opportunities identified in the SWOT analysis also strengthened this decision. Because the redesigned board minimizes piece displacement, it creates a smoother, less interrupted, and more enjoyable gameplay experience for all players. The design also allows for the potential of future additions to the design, such as with colour coding, textures, or possibly Braille. Additionally, this design solution could inspire the simple redesign of other board games to make all gameplay more enjoyable, while still keeping an affordable price. Together, these opportunities show that the chosen design not only solves current usability issues, but also future development and innovation.

Weaknesses and threats were also carefully considered before committing to this solution. Although the solution still requires those with tremors to physically hold and move pieces, players could move bigger pieces with more ease and wouldn't have to worry about knocking down surrounding pieces on the board. Rather than making a different game version for them to play (eg, online Catan), this allows the players to enjoy the game as it was meant to be played, with less difficulty. As well, although other design solutions can achieve the same outcome of increasing piece stability (eg, Velcro), they either negatively affect aesthetics or are less effective. Overall, the chosen design solution best maintains the original gameplay experience while improving stability and user experience.

### 2.2 Core functions

In the morph chart (see Appendix C) for this design solution, five different functions were identified. However, the core functions that guided the concept selection are pieces that resist accidental bumping force, ergonomic grip, and a reachable board. For each of these functions, we evaluated several possible means and selected the ones that best balanced feasibility, effectiveness, and preservation of the original gameplay experience.

For the first function of resisting accidental bumping force, three means were chosen for the solution, including magnets, holes in the tiles, and larger, heavier pieces. These were chosen because they were deemed the most feasible and effective. For example, the click-in mechanism would be significantly more difficult to prototype and might pose a greater challenge to remove the piece compared to the chosen options. On the other hand, placing holes in the tiles was an idea that was simple to prototype, and the hole depth could easily be varied for testing later on. As well, magnets were chosen because they reduce the accuracy needed to connect tiles; the tiles simply need to be in the vicinity of one another to stick together. Finally, other than the benefits mentioned in the ergonomic grip function section, heavier pieces would require a greater applied force to move than a lighter object.

To satisfy the core function of an ergonomic grip, means included in the final design included larger pieces, thicker tiles, and pieces with more edges. During research conducted in the empathize phase, it was found that larger pieces and tiles greatly help improve precision and reduce frustration for players with tremors [1]. As well, because extra edges reduce the amount of grip strength needed to hold a small object, this was chosen as an effective and very feasible means. These additional edges are naturally incorporated into the settlement, city, and road designs through the male connectors that interface with the tiles.

Finally, the means chosen to achieve the function of a more reachable board was to take out the ocean frame around the tiles, thus allowing for the game board size to remain consistent with the original while making each tile slightly larger to allow for greater ease of use and precision. This means was chosen because in the original game, the ocean border serves the purpose of containing the ports and holding the tiles together. With the redesigned board, tiles stick together through the use of magnets, and ports are their own small triangular tiles that can connect to the hexagonal tiles, eliminating the need for the ocean frame in its entirety. Many of the other means (eg, rotating board, different board layout) for this core function are overly complicated or change the familiar look of the game, ruling them out.

## 3.0 Defining Specifications

### 3.1 Needs and specifications

Legend
◉ = 9
◯ = 3
△ = 1

| What | | Catan players with tremors | Schools/Caregivers | How: ce required to grip on to the pieces | Force to put pieces into slot | Board Size | Force to detach piece | Piece Sizes | Length of Gameplay | Weight of pieces/dice/board | ndness of the pieces (edge radius) | piece/board lifetime | Board game price | Force to separate tiles | Now: Original Catan Board Game | Catan online games |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ↓ | ↓ | ↓ | ↓ | ↑ | ↓ | ↑ | ↓ | ↑ | ↓ | ↓ | | |
| | | | | N | N | cm^2 | N | cm^3 | hrs | grams | cm | yrs | $ | N | | |
| **1.0 Facilitate easy grip for individuals with dexterity issues** | 1.1 Tactile | 5.5 | 18.2 | ◉ | ◯ | | ◯ | | △ | | ◯ | | △ | | 2 | 3 |
| | 1.2 Pieces are large enough to pick up with limited dexterity | 16.4 | 16.4 | ◉ | ◯ | ◉ | ◯ | ◉ | | ◯ | | | △ | △ | 2 | 3 |
| | 1.3 Lightweight | 3.6 | 7.3 | ◯ | ◉ | | △ | △ | | ◉ | | | | | 5 | 3 |
| | 1.4 Easy to pick up | 16.4 | 12.7 | ◉ | △ | | | | | | | | | | 2 | 3 |
| **stability for sudden movements across** | 2.1 Pieces remain in place when nudge | 3.6 | 1.8 | ◉ | ◯ | ◯ | △ | | ◯ | △ | | | | ◉ | 1 | 3 |
| | 2.2 Pieces remain in an upright position | 3.6 | 9.1 | ◯ | ◯ | | | | | | | | | | 1 | 3 |
| **for people with tremor related** | 3.1 Colours are easy to distinguish, fonts and | 7.3 | 11 | | | | | | ◯ | | | | | | 4 | 4 |
| | 3.2 Easy to tell where each piece goes | 9.1 | 7.3 | | | ◯ | | ◯ | | | | | | | 3 | 4 |
| **4.0 Keeping the vital characteristic of Catan** | 4.1 Pieces do not change the rules of the game | 10.9 | 0 | | | ◯ | | ◯ | ◯ | | | | | | 5 | 2 |
| | 4.2 Pieces do not change the look of the game | 12.7 | 11 | | | ◉ | | ◉ | | | ◯ | | | | 5 | 2 |
| **5.0 Keeping the** | 5.1 The layout of the board allows for | 10.9 | 5.5 | | | ◉ | | △ | ◯ | | | ◯ | ◯ | | 3 | 1 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Importance | Catan players with tremors | 23 | 7 | 25 | 4 | 19 | 6 | 5 | 3 | 2 | 3 | 3 |
| | Schools/Caregivers | 27 | 12 | 17 | 6 | 16 | 4 | 6 | 5 | 1 | 3 | 4 |
| Competitors | Original Catan Board Game | 1 | 2 | 961 | 1 | 3 | 1 | 15 | 0.5 | 30 | 50 | 0 |
| | Catan online game | 0.7 | 0.5 | N/A | 0.5 | N/A | 1 | N/A | N/A | N/A | N/A | 0 |
| Target (delighted) | | 1 | 5 | 600 | 30 | 5 | 0.8 | 8 | 1.5 | 50 | 20 | 20 |
| Threshold (disgusted) | | 4 | 15 | 1200 | 10 | 3 | 1.5 | 20 | 0.3 | 5 | 80 | 60 |

*Fig. 3.* QFD

The key stakeholders for this project include players with hand tremors, as well as the family members, friends, caregivers, and school staff who play alongside them. These primary users prioritize independence, stable gameplay components, and the ability to participate fully without feeling like they are slowing down or disrupting the game. Secondary stakeholders such as game studios, manufacturers, vendors, and the broader Catan community value feasibility, safety, affordability, and preserving the original essence of Settlers of Catan. The analysis for this section can be found in Appendix D.

From these groups, several major stakeholder needs were identified:

1. Stability and control of the board and pieces
2. Ease of handling for reduced fine-motor ability

3. Accessibility and independence during gameplay
4. Comfort and reachability across the play area
5. Preservation of the social, familiar feel of Catan

These needs align directly with the project specifications. For example, the force required to grip and move pieces supports the need for stability: if a player accidentally bumps a tile while reaching across the board, the increased movement force ensures it will not shift unintentionally, while remaining manageable for intentional movement. The force to separate tiles follows a similar logic in that the magnets should be strong enough to prevent unwanted motion, yet not so strong that players struggle to separate tiles. Some requirements are less obvious at first. The edge radius, for instance, matters as sharp or narrow edges are difficult to grasp and can cause slipping. A larger, rounded edge improves grip security and makes handling more comfortable for users with tremors. Likewise, increasing piece size and movement force may seem counterintuitive, but both directly enhance stability and prevent accidental displacement during gameplay.

### 3.2 Metric Synergies and Tradeoffs

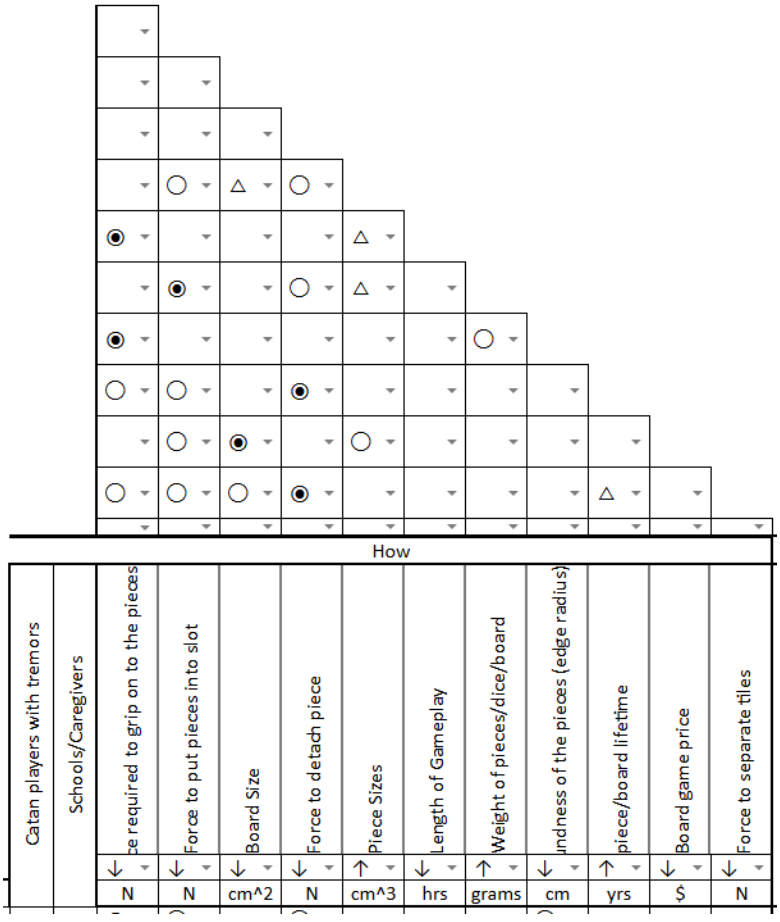


*Fig.4* . QFD Metric synergies

There are multiple strong correlations between the size of the piece and other specifications. For example, increasing the size of the piece allows for easier grip, thereby increasing the surface area that can be gripped. This, in turn, increases the amount of force you can exert on the piece, making it easier to grip onto and remove from a tile. With board size, one important synergy was between the piece sizes and the board size. While decreasing board size is desirable, this would come with the trade-off of making tiles and pieces smaller. However, by redesigning the outer water piece, the size of the tiles could be increased.

There were several important trade-offs that had to be made between the force to manipulate pieces and the implementation of magnets. Ideally, minimal force should be used to insert a piece, while it should be rather difficult to detach it, thus preventing accidentally knocking them over. To make insertion easy, magnets were a part of the original design for roads and settlements, but were not ultimately feasible. With six settlement and road slots, a minimum of 6 additional magnets would need to be added to a tile, while a magnet would be added to each piece, drastically increasing the weight of components. This would, in turn, increase the force needed to grip and lift pieces. To address this, magnets were added only to connect tiles, while deeper slots for roads and settlements were used.

### 3.3 Benchmarking

| What | | Original Catan Board Game | Catan online games |
|---|---|---|---|
| **1.0 Facilitate easy grip for individuals with dexterity issues** | 1.1 Tactile | 2 | 3 |
| | 1.2 Pieces are large enough to pick up with limited dexterity | 2 | 3 |
| | 1.3 Lightweight | 5 | 3 |
| | 1.4 Easy to pick up | 2 | 3 |
| **stability for sudden movements across** | 2.1 Pieces remain in place when nudge | 1 | 3 |
| | 2.2 Pieces remain in an upright position | 1 | 3 |
| **for people with tremor related** | 3.1 Colours are easy to distinguish, fonts and | 4 | 4 |
| | 3.2 Easy to tell where each piece goes | 3 | 4 |
| **4.0 Keeping the vital characteristic of Catan** | 4.1 Pieces do not change the rules of the game | 5 | 2 |
| | 4.2 Pieces do not change the look of the game | 5 | 2 |
| **5.0 Keeping the** | 5.1 The layout of the board allows for | 3 | 1 |

*Fig. 5.* QFD Now vs. What

To determine the importance of the proposed design solution, it must be compared with existing solutions for benchmarking purposes. Current competitors include the original Catan game board, as it already considers tile movement by adding the sea borders. A second competitor is the online versions of Catan, which removes concerns of pieces moving out of place completely. By comparing these competitors to

the stakeholder requirements (see Appendix A), improved grip (R.1), stability under tremors (R.2), intuitive play (R.3), maintaining the essence of the game of Catan (R.4), and board reachability (R.5), it becomes clear where the proposed solution is more accessible than competitors.

Evaluating the original Catan board game against stakeholder requirements (R.1–R.5) highlights its strengths in maintaining the essence of Catan and defining gameplay norms. However, the original game board does not remain in place during gameplay, and pieces often end up moving. When playing with tremors, the pieces move more often, and it becomes difficult to maintain the gameboard. The pieces are small and can easily be placed incorrectly. The board size means players must reach across the board to place pieces; however, the size of the board is not a big issue, as the size is still within average arm's reach. The original Catan board requires larger, more grippable pieces, stabilized tile/piece placement, easy set-up/take-down and "fail-safes" for mistakes made by tremors.

The online version of Catan automatically removes the need to address requirements like grippable pieces and piece stability. However, there is an added concern of how tremors could affect online game play with a mouse or touch screen by resulting in pieces being placed incorrectly and not being able to fix them due to restrictions by the program. The online version also does not embody the requirement of maintaining the essence of Catan, which includes social interaction, making trades, and playing the game with friends. Additionally, some of the stakeholder values are compromised as the players may feel forced to play online due to a disability and have a disadvantage. The online version of Catan needs to appeal to the social aspect of Catan and the interactions when making deals with other people. It also needs to appeal to users with tremors by finding a way to ensure pieces end up in the correct spot despite tremors.

Comparing the current competitors defined what was important to focus on when reiterating the Catan game board. The proposed solution should improve the stability of pieces, enlarge pieces, add tactility for grip, maintain the reachability of the board and focus on the values of the stakeholders, like the importance of maintaining dignity and the interactions and physical aspects of the game. This comparison narrowed down what the current solutions lack and what the proposed solution should embody to become better than those currently on the market.

The original version of Catan falls short in many measurable requirements. The road sizes of the board are 5mm x 5mm x 25mm [2], the cities are 10mm x 19mm x 19mm [2], settlements are 10mm x 14mm x 12mm [2], and the tiles are 4mm per side [2]. The pieces that are used throughout the game, especially roads, are very small and, in turn, very light. This means it is difficult for players with tremors to place them during gameplay, and also means that they would move around more easily. Additionally, the force required to move pieces from their spot is very small, which means that slight disruptions can cause the whole playing board to be disrupted. Although it is important that pieces can be easily removed if they are incorrectly placed, they must not be too easily moved by unintentional forces. The original game is around 15"x16" [3]. At this size, gameplay is possible for most as the average reach of an arm is around 25-30" [4], meaning the board is currently at an optimal size. When considering online versions of Catan, many of the measurable aspects of the game are removed. There is no need to test the grip of pieces, their size, board size or force to move pieces. There may be new barriers, such as the error correction of the mouse or screen being used, the force it takes to position a piece on the screen, or how much the screen can zoom in/out. Therefore, the proposed solution must be the optimal solution in terms of all measurable aspects of the game. While each competitor satisfies certain aspects of gameplay, neither solution meets

the measurable specifications needed to support players with tremors. The original Catan producer does not mention specific grip-force values, exact stability thresholds, and material weight distributions, which means assumptions were made for these values, and online game play differs between users and devices.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Importance | Catan players with tremors | 23 | 7 | 25 | 4 | 19 | 6 | 5 | 3 | 2 | 3 | 3 |
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| Threshold (disgusted) | | 4 | 15 | 1200 | 10 | 3 | 1.5 | 20 | 0.3 | 5 | 80 | 60 |

*Fig. 6.* QFD Targets and thresholds

There are two performance levels considered in the QFD: the targets (delighted), ideal, desired performance and the thresholds (disgusted), the minimum acceptable performance. These values guide design decisions in the second half of the project, and the choices/changes made embody the problem space's stakeholder requirements. Each of the "how" targets is based on stakeholder requirements, and their targets and thresholds will be determined similarly. The piece size target should be a size that is easy to pick up, regardless of hand size, and is proportioned to make the use intuitive; an exact-sized object that is easy for people with tremors to hold is not defined, as it differs between each person. However, generally, if a piece is too large or too small, gripping it may cause issues. If the surface area of the piece is too small, excessive force may be needed, while too large and it may be uncomfortable to play with. Therefore, the target amount is the minimal force required to grip the piece under moderate tremors and small sudden outbursts. The stability of the pieces is based on how deep the inserts are, how tall the top half of the piece is and the strength of magnets used (if any). The target stability is that if the pieces were to be knocked by dice, fore arm or the shake of a table that they would remain in place. The pieces should at least remain in place as players are initially placing them down despite tremors. The board size is targeted at a size where players, despite some restricted span, can reach all aspects of the board without getting up, whereas the threshold is that players can interact with their cards, other players and pieces on their half of the board without moving.

The proposed solution incorporates larger and thicker tiles that stay together using magnets. This is due to the target and threshold defined by the QFD. The QFD also ensured a focus was placed on maintaining the stability of the pieces even when in their respective slots on the gameboard. The game board size remained the same despite the longer places, as the outer rim of the Catan tiles was removed and the ports were replaced by a separate piece. The original design and gameplay essence of the Catan game were maintained. After optimizing all measurable aspects of the physical Catan game, a focus was placed on ensuring the design met the defined constraints. The game was designed using 3D printing PLA, and the total estimated cost of printing the whole game was $50.0, which is less than the original price of $75.0 [5]. Additionally, the design remains within manufacturing capabilities and ensures safe gameplay despite the use of magnets. Overall, establishing these targets and thresholds ensures that the proposed solution is grounded in measurable performance improvements and directly addresses the accessibility gaps left by existing versions of Catan.

## 4.0 Prototype Planning and Objectives

### 4.1 Planning Steps Before Prototyping

The steps taken before building the prototype to plan were developing a general idea of various issues that are encountered while playing Catan, and then relating that back to the stakeholders. During the early planning stages of the project, a list of the key aspects that would affect the gameplay for any player with tremors was developed. This included the card trading aspect, dice rolling mechanism, placement of various pieces, stability of the tiles, and resource management.

The assumptions made regarding physical aspects of the board game that would affect the gameplay were the size, weight, and stability of the various game pieces, especially the tiles. Catan consists of many interrelated subsystems: the hexagonal resource tiles that define the base of the board, the game pieces (roads, settlements, cities, and robber) that are strategically placed onto the tiles, the dice that determine the resource distribution, and the cards for resource trading. After analyzing the performance of the Catan tiles/pieces, how easily they were unintentionally moved, and how much precision was required to place down the specific pieces, the focus for the initial prototype was the design of the tiles and the game pieces that interact with the tiles, as they form the base of the game and are critical to testing gameplay.

The prototype integrated the improved subsystems of Catan by ensuring that, through the use of SolidWorks design and magnets, the pieces would click together with ease. The failure modes anticipated for the stakeholders were the placement of the pieces on the tiles and the pieces being accidentally shifted. While developing the prototype, the design factors considered were the thickness, weight, and placement of the pieces. Having pieces that were too thin would make it difficult for players with tremors to pick up and place down the tiles. The design of how each piece fits together was also an important consideration, as the mechanism had to be secure enough to keep the tiles locked into place, but also easy enough to disconnect for disassembly purposes.

To optimize the design, multiple prototypes were created where certain features were reiterated, such as the dimensions of the chamfers, the 3D aspect, and the tile connecting mechanism. Each redesign considered the thickness and weight of the pieces, ensuring that they were optimal to pick up and place into their corresponding slots or connect with other tiles.

### 4.2 Intended Test and Link to Specification

Based on the specifications, the primary objective of the prototype was to increase the amount of lateral force it takes to move each piece, while keeping the forces required to insert and remove the pieces too high. The intended test was to measure the amount of lateral force required to move each piece of the board, with the objective being to determine how the design affects the overall ability of the game being able to withstand any unintentional movement. The components of the game that were being tested include the tiles, settlements, cities, roads, and ports. If the force measure was greater, it would indicate that the pieces have more stability and are more resistant to any accidental movement. This connects the specification of force required to detach a piece, which should be increased in the redesigned version of Catan, as the intended purpose of the design was to increase the overall stability of the various components of Catan. This includes the pieces and tiles being resistant to movement by the dice,

movement of the board, or any movement by a person. The test also connects to the strength of magnets specification, as that has a direct impact on the stability of the tiles altogether, as well as how detachable they are.

### 4.3 Prototype Description

*Fig. 7.* First prototype

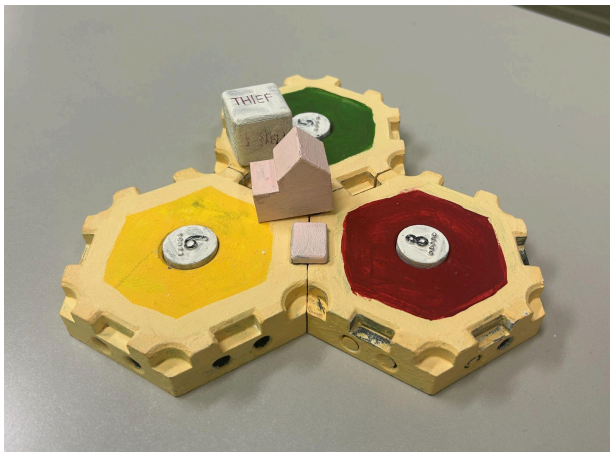



*Fig. 8.* Second prototype

Two prototypes were developed for this project. Both prototypes were designed using SolidWorks and printed with PLA filament. Both prototypes have the same dimensions, with each side of the tile being 50mm long and 20mm thick, making the pieces large enough to pick up with limited dexterity (R1.2 in Appendix A). The centre of each tile has a 20mm diameter and a 5mm indent for the numbers to be placed on the tile, while staying in place. At the corners of each tile, there is an indent in the shape of a third of a circle, and as three tiles meet, they form a slot for the settlements and cities to be placed between the tiles securely. Each city is 30mm in height and 20mm in width, and each settlement is 30mm in height and 30mm in width. Both have an extrusion on the bottom that is 15mm in diameter and 7.5mm in depth, and fit into the indent created by three connecting tiles. The roads have a base that is 15mm by 5mm by 10mm and inserts between two tiles. There is a large enough error tolerance to ensure that the settlements and cities require a small amount of vertical force to be placed or removed, but require a large amount of lateral force to be moved (R1.4, R2.1, R2.2 in Appendix A).

The first prototype, as shown in Figure 7, includes a 3D aspect to each tile that represents the resources. After further consideration, this design was refined to exclude the 3D resources to ensure that the numbers on each tile are visible. The slots for the magnets were also altered from being a 10mm by 7.5mm by 10mm indent to being two circular indents with a depth of 10mm and a diameter of 7mm.

Figure 8 shows the refined, final prototype, with the included pieces. Each component is large and colourful to ensure that players with tremors are able to pick them up easily, and the indents on the tiles make it clear where each piece is supposed to be placed [6]. The pieces do not require a large amount of force to be inserted or removed into the indents, but do require a considerable amount of lateral force to be moved out. The magnets are strong enough to keep the tiles connected, and do not require a large amount of force to be separated, which keeps the tiles user-friendly and accessible for players with varying levels of hand strength.

## 5.0 Engineering Analysis

### 5.1 Constraints Description

The specification being investigated is the lateral force required to detach a tile piece from 2 other tiles. This involves finding the force required to pinch a tile and proceeding to pull it apart. During the disassembly of the game, this action must be repeated a number of times. With essential tremors, the primary cause of tremors is the engagement of muscles. For stakeholders with this condition, the excessive force necessary to pull pieces apart will diminish the game experience. However, the contrary is also undesirable, as accidental bumps can also separate tiles.

### 5.2 Analysis approach and results

The analysis was done by hand using physics principles. To generate enough force to detach a tile, the magnetic force between the tiles must first be found. There are two magnets on each side of a tile, so a tile connected with two other tiles has four magnetic connections. Additionally, users will need to hold the tiles while pulling. If zero force is exerted to pinch the tile, the grip cannot be maintained and pulling force cannot be exerted. Thus, the force necessary to pinch a tile such that the resulting friction force is greater than the pulling force must also be found.

The magnets used in the prototype did not have a precise magnetic flux density measurement; thus, an assumption was necessary. Generally, small neodymium magnets were found to have a magnetic flux density ranging from 0.2 T to 0.6 T, so an approximation of 0.4 T was made. The coefficient of friction between skin and PLA was found to vary depending on texture density. While there is no specific texture density value, the coefficient of friction was estimated to be approximately 0.50 as the texture on the printed tiles was most similar to that of the 75% texture density [6].

To find the magnetic force, a simple formula can be used due to the fact that the two magnets are of the same material and have negligible distance between them when connected [7]. For the friction, the pulling force found to be necessary was used to find the normal force, equivalent to the pinching force, that was needed. The calculations can be found in Appendix E.

The analysis yielded a pulling force of 24.9 newtons and a pinching force of 17.8 newtons. This is equal to about 2.5 kg and 1.8 kg, respectively. Human fingers are physically capable of producing much higher forces [8]; thus, a relatively low level of exertion is needed to separate tiles in the design. In the context of stakeholders with tremors, this is a good thing, as magnets facilitate the needed stability while also being easy to pry apart. Moreover, these values are approximately 20 newtons, the target threshold stated in the QFD.

# 6.0 Testing

## 6.1 Test Planning

The p diagram analysis indicates the input signals, noise variables, quality measures, targets, experiments, and parameters, and it is presented in Appendix F. The primary goal of the redesigned Catan pieces was to increase the overall stability of the game, while keeping the individual placement of each piece simple and accessible. This is quantified by the quality measures: the force required to detach pieces and the force required to insert and remove the pieces into the slots. The targets of the resigned game are to minimize unintentional movement of pieces across the board by ensuring stability of the tiles and game components, and to minimize the force required to grip onto the pieces. The experiments involved testing the amount of lateral force required to move the tiles, roads, settlements, cities, and the robber. The parameters box shows the variables that can be controlled, but can also be changed. The parameters can be divided into two categories: the magnetism and the physical design of the pieces. The magnets can vary by the magnetic grade, the magnet size (diameter x thickness), and the number of magnets per tile. The physical design can vary by the edge radius, the slot dimensions, the weight of pieces, the thickness of pieces, and the size of pieces. Additional parameters also include the angle of the force applied, as this affects how difficult it is to remove the pieces from the slots.

The parameters that will be varied in the test are the slot dimensions, the weight of the pieces, the thickness of the pieces, the size of the pieces, and the angle of the applied force. The parameters that will be held constant are those relating to the magnets to isolate the effects of the mechanical fit and the edge radius. The major noise parameters that are not accounted for in the test and will become part of the variance are the printing variance (differences in dimensioning and material), which will contribute to how well each piece fits together. This would have an impact on the data because it would give each tile slight variations in components, such as the indent dimensions, surface conditions, and weight, resulting in extra scatter due to friction and the exact fit of the pieces together.

## 6.2 Test Protocol

*Fig. 9.* Testing the two games

To evaluate whether the redesigned Catan board improves stability for players with hand tremors, several quantitative force measurements were performed on and measured on the pieces of both games. The objective of this testing was to determine whether the redesigned, scaled-up pieces provided increased stability during gameplay by requiring greater force to move.

Force measurements were obtained using a force gauge operating at a sampling frequency of 100 Hz, with a measurement range of 0–50 N and an accuracy of ± 0.25 N (±0.5% FS). All readings were logged and stored using the gauge’s internal data recording

system. Testing took place on a level, rigid table. The game board was secured to prevent unwanted movement. Each Catan piece was placed in its standard position on the board. The force gauge was mounted so that the probe contacted the piece laterally, parallel to the table surface. Before each trial, the gauge was zeroed with the probe resting against the jig to ensure consistent baseline measurements.

Two participants assisted with the setup and testing process; however, all force measurements were performed by the same individual to maintain consistency. The tester followed standardized instructions:

1. Place the game board on a level, rigid table.
2. Secure the board so it does not move.
3. Position the Catan tile in its usual location on the board.
4. Mount the force gauge so the probe makes contact with the piece and at a consistent direction (lateral push parallel to the table surface).
5. Zero the force gauge with the probe touching the jig (no load on the piece) before each trial.
6. Apply a horizontal push over a 10 cm displacement.

Three trials were conducted for each dependent variable, and each trial was recorded independently. The force gauge remained on the ground throughout all testing to maintain a fixed orientation and minimize experimental variability.

Assumptions for this protocol included consistent push direction, constant friction between the piece and the board surface, and no rotation of pieces during the application of force.

### 6.3 Test Data

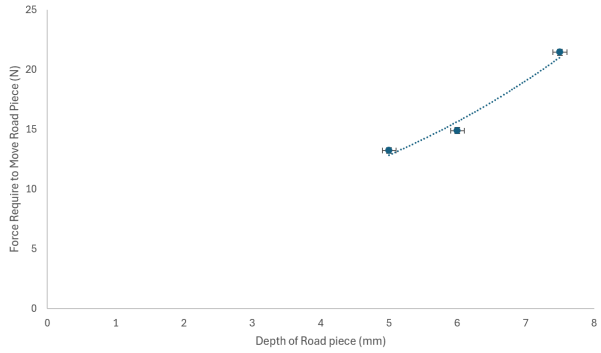



*Fig. 10.* Scatter plot of the lateral force required to move a road piece versus its depth. Vertical error is ±0.25 N [9].

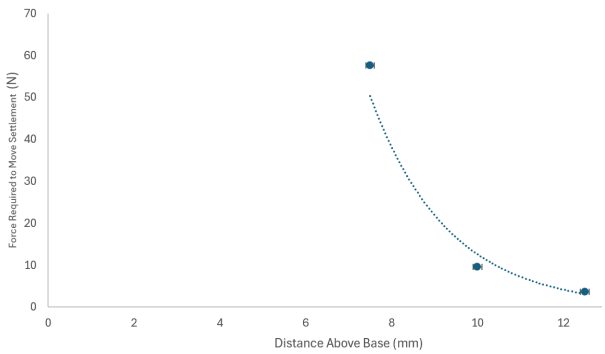



*Fig. 11.* Scatter plot of the lateral force required to remove settlement vs distance of application above base. Vertical error is ±0.25 N.

### 6.4 Interpretation of Data

The collected data indicate that the redesigned version of Catan provides more stability against unexpected lateral forces. Regarding the main requirement, which is to increase the amount of lateral force required to move the pieces so that players with tremors are less likely to accidentally shift them, the design performs strongly. The collected data for the roads and settlements indicate that the redesigned pieces provide an additional layer of stability to the game.

The design performs well with the requirement that was the focus of the test, which was to increase the amount of lateral force required to move the pieces out of the indents, which corresponds to the force required to detach the pieces. Figure 10. shows that increasing the depth of the roads produced an increase in lateral force required to move it, indicating that the further the road is into the slot, the more resistance the piece will have to accidental motion. The settlement to tile connection also meets the stability requirement, as the measured lateral forces in those configurations are higher than in loose configurations, indicating resistance to accidental displacement. This is shown in Figure 11.

Based on the testing, there should be slight revisions to the design. As shown in Figure 11, it takes considerably less force to displace the settlement when it is moved from the top of the piece. This means that ideally, the settlements should be made slightly smaller in height to avoid accidental displacement. This will lower the moment arm and decrease the susceptibility to accidentally being knocked over. Simultaneously, the base should be maintained to continue to provide stability to the settlement structure.

Limitations of the testing include that only a limited number of parameters were tested for each design variable (slot dimensions, piece size and thickness, piece weight, and height of applied force). As a result, potential non-linear effects between these points may not have been captured, which makes it difficult to determine the most effective design parameters. Many noise parameters were not controlled, including the printing variance in dimensions and material properties. Differences in the printed slot width, piece size, and surface finish may impact the fit and friction between the components. These factors may add scatter to the measurements and may slightly alter the data collected. The testing was conducted with constant variables, such as the angle of force applied (90°), the technique of force application, and the surface it was tested. In practice, these factors would all be varied, and each player will apply forces to the pieces differently, with varying hand strength, dexterity, and precision on surfaces with different friction. The results from the data do not depict the pieces in every scenario, only in an ideal setting.

In order to gather a more detailed collection of data regarding the effectiveness of the prototype, more qualitative testing would be conducted. These tests should involve people with tremors to gather more insight into whether the design is not only usable but also enjoyable to use.

## 7.0 Reflection, critique, and next steps

### 7.1 Summary

This report documents the design and the testing of the redesigned Catan pieces. The new design focuses on a physically stable and user-friendly prototype of the Catan game that uses magnets to attach the tiles and slots for the pieces that are placed on top of the tiles.

If realized into a fully functional product, the design would create value for the users by providing an inclusive and entertaining playing experience for players with tremors, while also keeping the true essence of the Catan game. The design enhances the playing experience for all players while instilling confidence in players with tremors by facilitating dignity and independence within the gameplay.

The key features of the final design are board stability, piece stability, and ergonomics. Board stability is ensured through this design by the inclusion of magnets to connect the tiles. This eliminates the need for the ocean frame, thus reducing the surface area of the board, keeping the game reachable and accessible for players while also keeping the game engaging. The pieces are stable due to the indents within and between the tiles, which minimize accidental movements and facilitate clear placement of each piece, therefore making the gameplay efficient while also accommodating individuals with tremors. Each piece was designed to be larger and heavier with thicker tiles to improve the grip for any player with limited dexterity. This helps players maintain dignity as it allows players with tremors to participate in the game without worrying about knocking down pieces or slowing down the game. The design also keeps all of the same rules as the original Catan, which allows for competitive and fair gameplay with a large emphasis on social connection.

### 7.2 Reflection

The initial prototype testing concluded that the magnetic connection between tiles, combined with the indents in the tiles for the pieces, enhanced the piece stability, which addresses the primary user need from the first Empathize phase. The next steps for this design would be to use the data found during the testing phase to develop the ideal balance between the two competing quality measures, the force to detach pieces and the force to put the pieces into the slots. The prototype has succeeded in increasing the stability of the game, which may have compromised the user value of efficient gameplay if the pieces are too difficult to insert into or remove from the slots. During the next cycle of the Empathize phase, a focus would be placed on ensuring the design aligns with user-specific needs. This would be done by conducting qualitative tests to collect feedback from Catan players, testing for perceived effort and whether the prototype feels easy to handle and testing for ergonomic endurance to determine whether the increased size and weight of the pieces made the game too tiring to handle for the entire duration of the game. Overall, the design process would shift from being focused on the functional capability of the prototype to validating user satisfaction to ensure that the final iteration of the design is not only usable but also enjoyable for all players with varying levels of dexterity.

# Appendix A

| Description | Details |
|---|---|
| R.1 Facilitate easy grip for individuals with dexterity issues | R1.1 Tactile<br>R1.2 Pieces are large enough to pick up with limited dexterity<br>R1.3 Lightweight<br>R1.4 Easy to pick up |
| R.2 Maintains stability for sudden movements across the board | R2.1 Pieces remain in place when nudged<br>R2.2 Pieces remain in an upright position |
| R.3 Visually simple for people with tremor-related issues | R3.1 Colours are easy to distinguish, fonts and symbols are readable<br>R3.2 Easy to tell where each piece goes |
| R.4 Keeping the vital characteristic of Catan | R4.1 Pieces do not change the rules of the game<br>R4.2 Pieces do not drastically change the look of the game |
| R.5 Keeping the board reachable from all areas for people with mobility issues | R5.1 The layout of the board allows for effortless reach wherever necessary |

*Fig. A1.* SWOT analysis conducted in the ideation phase.

# Appendix B

**SWOT analysis**

| Ideas | Strength | Weaknesses | Opportunities | Threats (other alternatives) |
|---|---|---|---|---|
| Claw machine picking up Catan pieces | • Minimal movement required<br>• Effective once working<br>• Provides a sense of independence for users<br>• Could have adjustable sensitivity features<br>• Turns accessibility aid into a cool game upgrade rather than a limitation | • Difficult to execute<br>• Expensive<br>• Requires a power source<br>• Large and bulky, difficult to transport<br>• High risk of mechanical failure<br>• Requires intricate design<br>• Could be really chunky and make it easier to knock pieces over<br>• May distract from the gameplay<br>• Much slower and needs more care than when using hands | • Fun idea,<br>• could make gameplay more engaging/unique<br>• Can use with other games<br>• Could integrate it with an app for voice-controlled automation<br>• Can customize the claw machine look | • Players may find it frustrating or impractical<br>• High maintenance and durability issues<br>• Can be used for unintended purposes<br>• Magnetic pieces are an easy alternative |
| Pieces that click into place on the board | • Clicky, stable pieces<br>• Highly feasible<br>• Effective in gameplay<br>• Offers satisfying tactile feedback, enhances user enjoyment<br>• Portable and easy to assemble<br>• User friendly<br>• Cheap to make (no batteries or electronics needed) | • Time consuming to design each piece<br>• May be difficult for users to click it into place/pick the pieces up<br>• Users still have to carry small pieces and drop/click them into correct spot<br>• Designing perfect tolerances for clicks is tricky (too tight or too loose ruins gameplay)<br>• Could wear down over time, reducing the clicky feel | • More enjoyable play<br>• Less time fixing knocked over pieces<br>• The physical clicking of the pieces can align with a digital version of the game in the future<br>• Can incorporate color coding, textures, or Braille for multi sensory accessibility<br>• Could inspire sustainable modular board design (swappable tiles, fewer parts lost) | • Magnets or Velcro may outperform in ease of use or durability<br>• Larger pieces<br>• The pieces may be either too tight or too loose if incorrectly designed<br>• The pieces could deform over extended periods of use<br>• Increased use of plastic parts may lead to more plastic pollution<br>• Competitors could replicate the idea quickly with cheaper materials |
| Card trading app | • Simple to use once set up<br>• Software-based (no physical modification)<br>• Portable across devices<br>• No need for any fine motor control | • Requires all players to use it<br>• Inconvenient for some users<br>• Excludes those without phones<br>• May reduce physical interaction<br>• May make the game less fun and interactive<br>• Need to know how to use tech<br>• Notifications on devices mid-game play could cause a distraction | • Less time spent moving cards around, faster play time<br>• Expansion features (tracking, digital enhancements)<br>• Can use with other games<br>• Could integrate with the Catan app<br>• Could become voice-controlled trading<br>• Could suggest fair trades and help with resource management | • Larger physical cards<br>• Technical malfunctions or app bugs<br>• Dependence on device compatibility and availability<br>• People may have difficulty understanding how the app works<br>• Wifi or battery problems would stop gameplay |
| Light up roads on press (lights up to your colour instead of placing the road) | • Eliminates need for small physical pieces<br>• Reduces impact of hand tremors<br>• Integrated one-piece board<br>• Maintains standard game size and portability<br>• Glowing colors add excitement and visibility<br>• Integrates the tactile "press" action, keeping users physically engaged without requiring precision | • Difficult to execute<br>• Requires a new custom built board, increasing cost and complexity<br>• Cost<br>• Technical malfunctions<br>• May drift too far from the classic board game feel<br>• Less flexibility in the game set up<br>• Needs a power source (battery or USB) which could die mid-game<br>• Moves away from the tactile, "classic Catan" feel that traditional players love | • Could modernize and gamify Catan, attract younger/techy players<br>• Makes the game more enjoyable<br>• Allows digital integration: Bluetooth or app tracking for automatic scoring | • Click in or magnetic pieces might be simpler, cheaper, and more reliable<br>• Some players may find light effects distracting or overstimulating<br>• Electronic waste concerns or limited battery life<br>• Larger tactile or textured pieces could achieve similar accessibility benefits without tech |

*Fig. B1.* SWOT analysis conducted in the ideation phase.

# Appendix C

| Functions | Means | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Pieces resist accidental bumping force** | Magnets | Slots in tile pieces | Click-on mechanism | Larger and heavier pieces | Pieces that are level and stable | Symmertrical pieces like cubes for loose pieces | | |
| **Ergonomic grip** | Textured components | Different materials | Larger pieces | Pieces with more edges and less flat surfaces | Lightweight | Thicker tiles | Shape pieces with finger grooves for more comfortable handling | Use silicon or rubber create a non-slip grip |
| **Easy to use** | No changes to the rules of the game | No changes to the colors or "look" of the game | Easy to remove settlements and replace them with cities | Easy to place pieces and connect game tiles | Easy to move around the knight | Include clear visual labels or icons to quickly identify piece types. | Easy to set and up remove the tiles | |
| **Reachable board** | Smaller tile sizes to take up less space | Less of the ocean frame around the tiles | Rotating board | A differently oriented board (pieces are arranged in a way that makes it easy to reach all places on the board) | Pieces and cards are located in an area that is close for all players | Rollers that lock to move board closer to players when needed | | |
| **Easy to store** | Easy to disassemble the game | Game components can be organized in the game box | Game pieces can fold into small pieces | Tiles that are easy to stack and lay down flat | Game is stored in an intuitive fashion where pieces are not damaged during transport | Components nest together for compact storage that ensure pieces don't shake around a lot | | |

*Figure C1.* Morph chart

# Appendix D

| | | 1.0 Facilitate easy grip for individuals with dexterity issues | | | | 2.0 Maintains stability for sudden movements across board | | 3.0 Visually simple for people with tremor related navigation issues | | 4.0 Keeping the vital characteristic of Catan | | 5.0 Keeping the board reachable from all areas for people with mobility issues | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | catan players with tremors | 1.1 Tactile | 1.2 Pieces are large enough to pick up with limited dexterity | 1.3 Lightweight | 1.4 Easy to pick up | 2.1 Pieces remain in place when nudge | 2.2 Pieces remain in an upright position | 3.1 Colours are easy to distinguish, fonts and symbols are readable | 3.2 Easy to tell where each piece goes | 4.1 Pieces do not change the rules of the game | 4.2 Pieces do not change the look of the game | 5.1 The layout of the board allows for effortless reach wherever necessary | | Total | Normalized | |
| **1.0 Facilitate easy grip for individuals with dexterity issues** | 1.1 Tactile | | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | | 3 | 5.454545455 | 5.454545455 |
| | 1.2 Pieces are large enough to pick up with limited dexterity | 0 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 9 | 16.36363636 | 16.36363636 |
| | 1.3 Lightweight | 0 | 0 | | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | | 2 | 3.636363636 | 3.636363636 |
| | 1.4 Easy to pick up | 1 | 0 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 9 | 16.36363636 | 16.36363636 |
| **2.0 Maintains stability for sudden movements across board** | 2.1 Pieces remain in place when nudged | 0 | 0 | 1 | 0 | | 1 | 0 | 0 | 0 | 0 | 0 | | 2 | 3.636363636 | 3.636363636 |
| | 2.2 Pieces remain in an upright position | 1 | 0 | 1 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 2 | 3.636363636 | 3.636363636 |
| **3.0 Visually simple for people with tremor related navigation issues** | 3.1 Colours are easy to distinguish, fonts and symbols are readable | 1 | 0 | 0 | 0 | 1 | 1 | | 1 | 0 | 0 | 0 | | 4 | 7.272727273 | 7.272727273 |
| | 3.2 Easy to tell where each piece goes | 1 | 0 | 0 | 0 | 1 | 1 | 0 | | 1 | 1 | 0 | | 5 | 9.090909091 | 9.090909091 |
| **4.0 Keeping the vital characteristic of Catan** | 4.1 Pieces do not change the rules of the game | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | | 0 | 1 | | 6 | 10.90909091 | 10.90909091 |
| | 4.2 Pieces do not change the look of the game | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | | 1 | | 7 | 12.72727273 | 12.72727273 |
| **5.0 Keeping the board reachable from all areas for people with mobility issues** | 5.1 The layout of the board allows for effortless reach wherever necessary | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | | | 6 | 10.90909091 | 10.90909091 |
| | | | | | | | | | | | | | Total | 55 | 100 | |

*Figure D1.* Pairwise - Catan players with tremors

# Appendix E

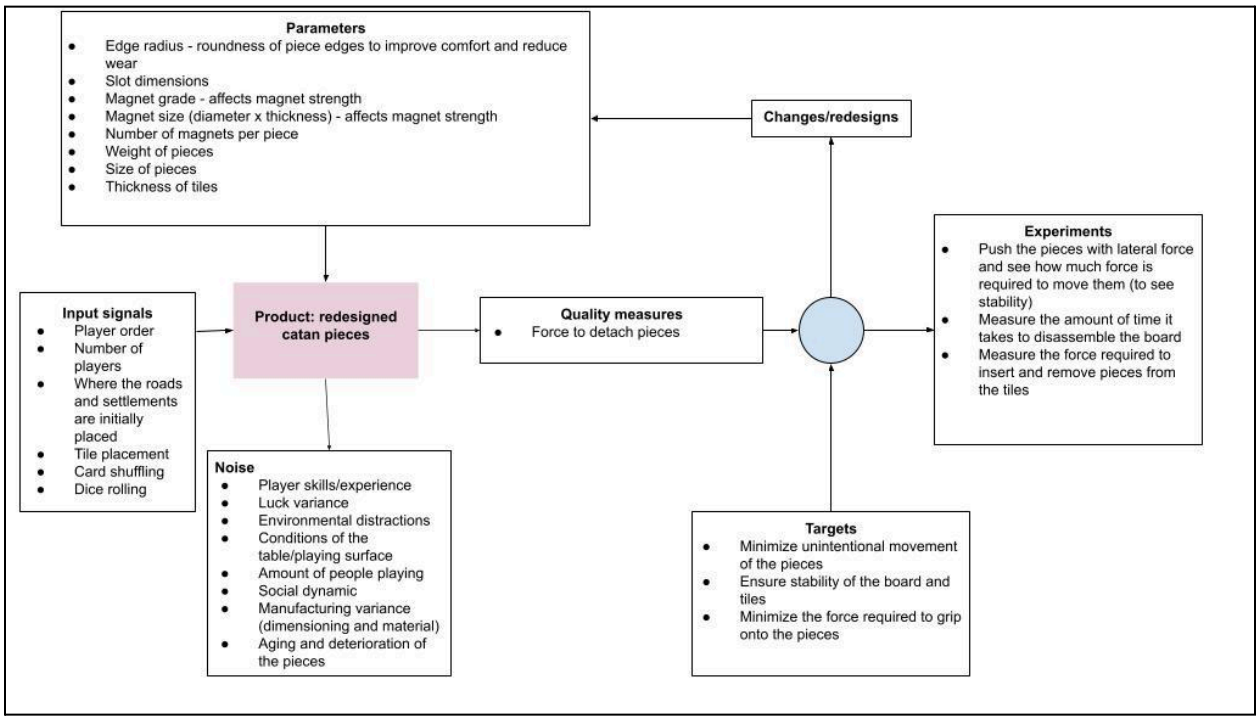



*Figure E1.* P diagram

# Appendix F

1. a) Magnetic flux density $B = 0.4\ T$

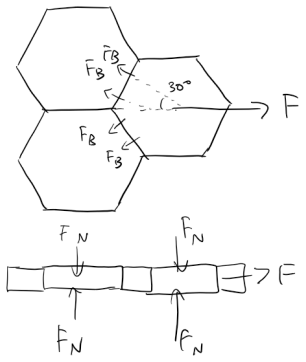
Radius of magnet $r = 0.006\ m$

Coefficient of friction between skin and PLA $\mu_{sp} = 0.70$

b) Forces necessary to pull apart a tile from two tiles.

c) Rigid bodies, weight of tiles is negligible, $\mu_0 = 4\pi \times 10^{-7}\ T \cdot m/A$

2. a)




b) Formula for force between two nearby magnetic forces is

$$F_B = \frac{B^2 A}{2\mu_0}$$

$$A = \pi(0.006)^2$$
$$= 0.0001131\ m^2$$

$$F_B = \frac{(0.4)^2(0.0001131)}{2(4\pi \times 10^{-7})}$$
$$= 7.20\ N$$

Pulling at angle

$$F = (4)(\cos 30°)(7.20\ N) = 24.9\ N$$

Necessary pinching force to separate tiles

$$\Rightarrow F_f \geq F$$

Otherwise grip lost

$$F_f \geq 24.9\ N$$
$$4\mu F_N \geq 24.9\ N$$
$$2F_N \geq \frac{24.9\ N}{2(0.70)}$$
$$2F_N \geq 17.8\ N$$

Thus, each hand must pinch with 17.8N of force to maintain grip on tile.

d) sigfigs are 3 throughout.

e) N for forces, Teslas for magnetic flux density

g) Pulling force of 24.9 N required and pinching force per hand of 17.8 N.

*Figure F1.* Calculations for engineering analysis of the force required to separate magnetic Catan tiles

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