# Interactive Tabletop Game Board


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## Statement of Originality

This report is submitted as part requirement for the degree of Computer Science & Artificial Intelligence at the University of Sussex. It is the product of my own labour except where indicated in the text. The report may be freely copied and distributed provided the source is acknowledged. I hereby give permission for a copy of this report to be loaned out to students in future years.

## Acknowledgements

I would like thank Dr Ronald Grau for his incredible contributions and support throughout the course of this project. I would also like to thank Mark Hooper for providing essential guidance and electronic knowledge based on a prior project of their own [31].

## Professional Considerations

This project meets all the specified requirements in the BCS Code of Conduct [2] and User Testing Compliance Form attached in Appendix 10.2. The hardware and materials used throughout this project are a mixture of common household electronics and basic construction materials. Participants of the user testing were not placed in dangerous environments in any capacity. Section 4 fully details the professional considerations and ethics of the project.

## Abstract

This project entails the development of an interactive game board, designed to facilitate a variety of games, enabling over-the-internet remote gameplay while introducing physical interaction, which would have a user-informed evaluation. This project was motivated by the general lack of personal interaction experienced over the COVID-19 pandemic. Background research on the use-case and sensory methods led to the creation of a prototype device comprised of a physical board and website interface that allow physically interactive gameplay between individuals over the internet. It was discovered that the chosen sensory methods and website interface design, while meeting the requirements of the project, presented challenges and shortcomings alike (such as electromagnetic interference and lack of stimuli within user interfaces), resulting in the conceptualisation of a second prototype for future study. As a result of this project's findings, it can recommended that further research into the realisation of the conceptual second prototype would provide valuable insight and experience into the creation of interactive remote gaming devices.

# Contents

# 1 Introduction

Tabletop board games have for the longest time provided a means for people to interact with each other and share experiences. They have always been one of the most accessible means of experiencing the 'thrill' of gameplay for anyone who can grasp the rules. Furthermore, nowadays people are able to share these experiences online, broadening the reach of these games further than ever before.

Be that as it may, online tabletop experiences are not wholly reflective of the traditional affair one may expect from in-person tabletop games. Tangible interaction between individuals is mostly lost, and not fully remedied through use of technology like webcams or microphones. This project aims to create a device which recreates some of those feelings.

The creation of a physical prototype board and accompanying software, capable of tracking physical playing pieces and updating an interactive game environment is this project's summarised objective. The hope of this project is that this device will enable a new means of physical interaction in the context of online tabletop gameplay. The device and supporting software will be designed with adaptability in mind, as to enable its integration into as many tabletop games as possible.

This prototype device will be evaluated through both internal testing to ensure functionality and user testing-based evaluation. This will provide invaluable high-level feedback, which will contribute towards development of the prototype device. This will also develop my understanding of human-computer interaction through the interactive device design and evaluation process. I will also use this project as an opportunity to express my software and hardware development skills, through use of electronic components and programming.

## 1.1 Motivations

The motivation for undertaking this project stems from my experiences with online tabletop gameplay, specifically online tabletop role-playing games. Typically, tabletop games enable physical expression between people, such as sharing laughter and contact with each other. These are tangible interactions which are challenging to reproduce over online communications. However, in these uncertain times, one cannot expect to always be capable of playing a tabletop game in the same place as others.

Hence, the need to engage in these social activities over an online connection will remain for the foreseeable future. This project aims to create a device which could help alleviate these downfalls, by establishing a new means of physical connection between people who are sharing an online tabletop game. The objective is to create a device, that can be implemented into most online tabletop games, providing a new dimension of physical interaction, will restore some of those absent feelings of human interaction.

## 1.2 Objectives

The purpose of this project is to develop an interactive board which can be used as a general-purpose tabletop game board. The evaluation of this prototype will be user-informed, which will be achieved through a user testing and feedback stage.

This project also aims to facilitate a means of tracking pieces on this prototype board, such that the board will display 'game states'. The board must be capable of changing these states through piece tracking and reflecting these changes in its display.

To facilitate this, some kind of web-based communication will need occur between the physical board and an online host storing the necessary visuals. The minimal functionality to enable gameplay would be the ability to display game environments and playing pieces on this website, and for the environment or piece positions to change in accordance with physical piece locations. The prototype will have a very simple website depiction, intended for flexibility in both means of display and game variety.

# 2 Background Research

## 2.1 TTRPG Use Case Research

To begin the project in good faith, it was important to obtain as much information from existing implementations as possible. Tabletop Role-Playing Games (TTRPGs) typically consist of at least two players interacting with miniature playing pieces on a standard tabletop. However, in some cases, TTRPGs incorporate use of technology like screens or projectors to depict environments. From preliminary research, a projection mapping example [38] stood out in particular, as it incorporated the use of an online tool called Roll20 [12], which I was familiar with.

Figure 1: D&D game leveraging the use of projection and online tools [38]

Figure 2: Example of a complex TTRPG instance [28]

In Figure 1, a projector is mounted overhead to display the 'map' for players to interact with. The players are able to use physical tabletop playing pieces to interact with the game environment. However, no piece tracking was being performed by any technology in this example, this was instead performed by the Game Master (GM) who sits behind the computer and inputs player positions to facilitate the flow of gameplay. This will not be replicated in this project's implementation, as the end-goal of this project is to enable play between individuals who are unable to be in the same place. This use case however, has informed the decision that projection is likely the most appropriate means of displaying a game environment for this project. A typical screen may present issues in the long term if one decided to introduce piece tracking electronics underneath said screen, resulting in potential detection issues from screen interference.

Figure 2 depicts a more traditional and complex TTRPG experience. If the GM was required to record the position of every piece element on this tabletop, there would likely be more time spent checking precise piece locations instead of playing the game. Thus, it is my belief that to simplify the tracking process slightly, specific piece locations should be established. One might notice in Figure 1, that a grid overlays the map. This establishes a finite number of piece locations to simplify and speed up gameplay.

To summarise, this research indicated that environment projection is likely the most appropriate means of displaying imagery, particularly during prototype development. Automatic piece tracking is essential, as reliance on a human to record positional data is not possible when players are not physically together. Finally, a finite number of piece positions should be established through a grid, as this will greatly reduce environment complexities and computational costs.

## 2.2 Technology Comparison Research

The following subsections comprise the background research findings regarding a means of tracking tabletop game pieces on a board.

### 2.2.1 Depth & Infrared Sensors

The initial intended direction of this project was the use of depth sensors. A notable implementation is Sony's prototype projector from 2016 [39], followed in 2017 with the release of the Xperia Touch [19].

Finding information regarding the architecture of the 2016 prototype proved challenging, but it is clear that it possesses both depth sensing and object tracking capabilities. The Xperia Touch on the other hand uses an IR sensor according its US Amazon listing [13]. Infrared emitters and sensors can be used to derive the distance of a subject relative to the position of a device. The Xperia Touch likely achieves this by emitting infrared light across an area, then uses an infrared sensor to detect where the infrared light is 'interrupted' by the presence of a hand. That positional data is then translated into actions understandable by the projected applications. Alternatively, an infrared emitter can be placed inside a particular object intended for interaction, which is then located by a sensor. This was the approach taken by the Touchjet Pond [27].

Other iterations have opted to use depth sensors to track precise hand positioning [32]. This requires very high precision to detect inflexions and pressure in one's hands. Though this is not applicable, as this project is looking to track object positions as opposed to hand gestures.

Microsoft's Kinect Sensor works under the same principles, and the initial intention of this project was to use a Kinect V2 camera to facilitate the tracking of pieces in a board game. A project was found that utilises the Kinect V2 [35], but this example implements object tracking, which will be discussed in Section 2.2.2. However, this approach was dropped in favour of more simplistic approaches that fulfilled the requirements the system aimed to achieve. Furthermore, preliminary research did not reveal any examples of successful integration between any Raspberry Pi model and the Kinect V2. If this depth sensor approach continued, the use of the Kinect V2 or a similar product would've likely proven imperative, due to the relatively high tracking accuracy and resolution of the sensor, in accordance with its cost and ease of accessibility. However, as mentioned, its reliability of working in tandem with a Raspberry Pi unit or similar would be questionable at best.

### 2.2.2 Object Tracking

As mentioned briefly in Section 2.2.1, an alternate skew on a computer vision is object tracking. This is the act of enabling a computer to identify objects based upon features such as colour or shape. An implementation [35] was found, which utilises a Kinect V2 camera system.

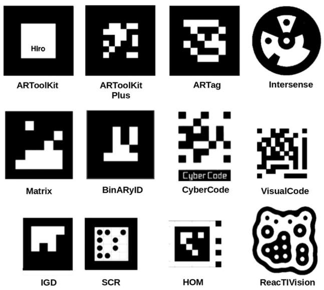


Figure 3: Examples of fiducial markers [25]

One means of identifying objects can be through the use of fiducial markers as seen in Figure 3. However, the use of fiducial markers is not practical for this project's use case, as one cannot rely on a camera to maintain line-of-sight with an identifying 'token' or 'tag' attached to playing pieces. Thus, a more complex implementation would be required to identify pieces by their shape or colour. This task requires more costly computation, potentially introducing latency and would most probably require a machine learning algorithm to 'teach' the system what all the pieces look like. Furthermore, adding new pieces would require the system to be retrained on the new sample set. To conclude, this approach, and likely any other founded in computer vision would be unsuitable.

### 2.2.3 Magnetic Sensors

To reduce implementation complexity, one can step away from solutions that rely on computer vision and instead use more traditional means of sensing environment changes. The next technology discovered thus far is magnetic sensors. The use of reed switches or Hall effect sensors [5] can determine positional data of pieces with ease in comparison to the previously discussed methods. A project implementing magnetic sensors into a chess board was found [29], with a video of a later iteration showing its capabilities [30]. This would inspire a new skew on research tactics, as chess provided a means of finding more real implementations of an interactive board beyond the idea of an interactive board by itself.

However, while this approach has significantly reduced complexity, as compared to the aforementioned methods, it has a serious shortcoming. Namely, that simple magnetic sensors are not capable of identifying pieces, only reporting their presence. The chess implementations found require additional logic to determine what pieces are in the corresponding locations, based on logical analysis of the specific game being played. This is inadequate for this project, looking instead to create a general purpose board that can facilitate any game that meets the physical constraints of the board.

To overcome this shortcoming, a sensor capable of discerning differing levels of magnetic energy could be used to report a unique strength reading to be identified. However, these sensors are notably more expensive than their more straightforward counterparts. Additionally, this would require playing pieces to contain a variety of magnets, all exhibiting different levels of magnetic strength. This could have a significant impact on the required size of playing pieces, and would require additional magnets of 'values' that are not yet allocated.

### 2.2.4 Proprietary Frequency Sensors

Following the developments with chess board-based research, efforts were redirected towards other chess board implementations. A particular product known as the Digital Game Technology (DGT) e-Board was found. Upon inspection of the internals, a proprietary frequency sensor system was found.

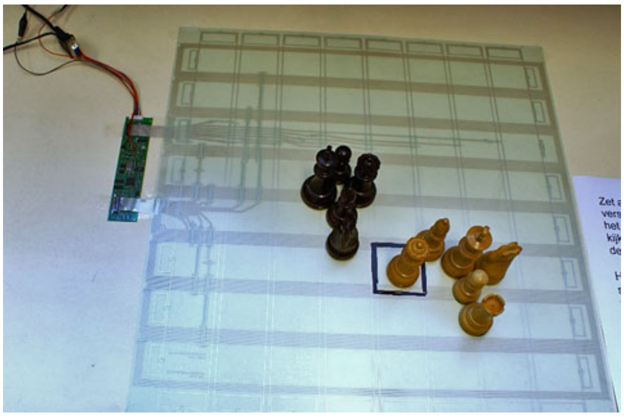

Figure 4: Internal circuitry of a DGT Board [3]

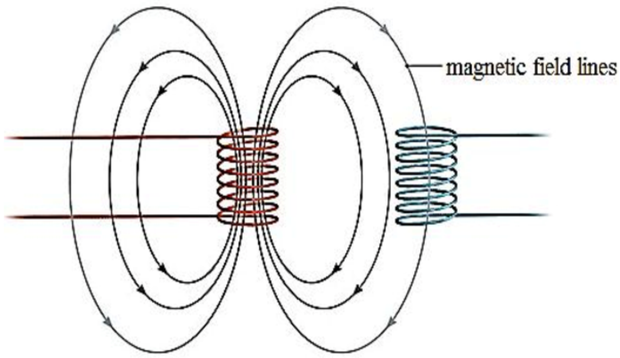


Figure 5: Diagram of single transfer via inductive coupling [37]

Figure 4 above depicts the internal sensory layer of a DGT chess board. According to the DGT Board Chessprogramming Wiki page [3], this is patent-registered technology but it was still inspected for the sake of inspiration. The relevant patent [21] has expired at this point.

It uses a conductive film, which runs underneath all the respective 'tiles' on the chess board, and relies on the playing pieces to have conductive coils inside them to act as passive LC circuits. The film is then 'scanned' through multiplexing and produces a frequency that is unique to any specific piece with a corresponding LC circuit. This results in an effect called inductive coupling, which the system then relays back to derive the positional data of the relevant piece. Figure 5 illustrates how a 'coil' can produce a magnetic field. Two coils will inductively couple provided that they are close enough, and will exhibit a greater level of inductance if each element shares a resonant frequency with one another. The 'tuning' of these LC circuits and frequency 'scanning' by the rest of the system is what causes the resonance inductive coupling to occur between the pieces and board.

This all results in a very capable and applicable system for this project's use case. Additionally, use of this technology is no longer hindered by the patent due to expiration, so simply taking the internals and finding a new means of interfacing with them may be a suitable approach. However, the DGT Boards are very expensive and would require full commitment for implementation in the project from the time of purchase. Hence, further research was required from this point into cheaper alternatives of an approach similar to this. Initially, cheaper Bluetooth implementations [20] appeared to be the most enticing. Although, this frequency-based sensory system would go on to inform the final implementation decision.

### 2.2.5 RFID Sensors

As opposed to the proprietary technology used in the previous approach, RFID is a commonly used and essentially identical standard. Following the second-hand advice from a few forum posts, it was found that RFID would be a nearly perfect solution for this project. Radio Frequency Identification (RFID) is a wireless connection that consists of tags and readers.

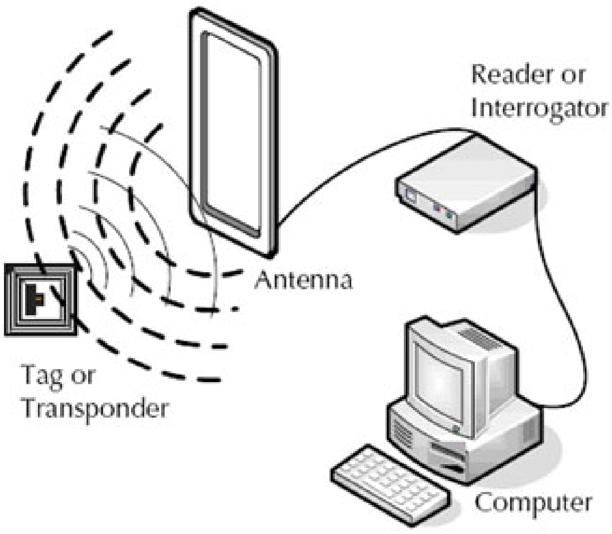


Figure 6: Illustration of how RFID communication works [9]

As depicted in Figure 6, a reader uses antennas to emit radio waves and receive resonant signals back from a tag in order to identify said tag. Either element of the system must be active, meaning that it must be powered in order to work, which typically manifests in active readers and passive tags.

Steve Hinske and Marc Langheinrich's 2007 project [28] provides a substantial analysis on the effect of using RFID technology, with radius crossover in particular being an important topic. Detection radius crossover will be discussed in further detail in Section 5.3.1. This project's implementation however, will be on a smaller scale and utilise discrete piece locations for the sake of easier translation between the physical board and web-hosted version.

Furthermore, an online video [24] was found, which uses a single RFID reader, with multiple antennae. Whilst the video did not explicitly mention one could assume that in this case, the antennae are being polled in sequence through multiplexing. Multiplexing is essentially the act of combining multiple communication signals into a single signal, though there are many ways to achieve this. One such way would be by combining all the the signals from all the antennae and producing a single signal which represents all others by representing them in another (typically compressed) format. Alternatively, one could also 'trick' a reader into reading from one antenna at a time but switching to another immediately after. The latter of which would be the most suitable for this project, as it would allow experimentation with polling speeds while also not risking sacrifice of data through any lossy compression.

# 3 Requirements Analysis

## 3.1 Primary Tasks

The following subsections outline the scope that this project has and will continue to explore.

### 3.1.1 Technology Comparison Stage

Early identification of the solution approach is imperative in order to ensure success of the prototype implementation. Sensory technologies considered include:

- Depth & Infrared Sensors
- Object Tracking
- Magnetic Sensors
- Proprietary Frequency Sensors
- RFID Sensors

The appropriateness of each technology for this application has been explored in detail. The findings are discussed in Section 2.2.

From this research, it was deemed that an RFID implementation would be most appropriate. This enables automated tracking of playing pieces, without the complications that come with computer vision-based approaches, while leaving the door open to expansion with additional pieces through simple programming.

### 3.1.2 Prototyping & Testing

This stage comprises all the actual development tasks required to put together a working prototype. The construction of a physical prototype, internal electronics and accompanying code are inevitable components. This project would be worth very little without producing at least a working proof of concept to facilitate a simple game experience. The end-goal of the project is to facilitate online play of a tabletop game, without sharing the same tabletop with one's fellow players. Hence, the creation of a prototype and subsequent functionality testing is an essential component of the project.

This should be achieved through the realisation of a typical 'board' with a discernible grid printed onto it. Preliminary research outlined in Section 2.1 concluded that the use of projection to display the game environment would be suitable. This would mean a material that is both light in colour and lacks patterns should be used. A high quality plastic such as a polycarbonate, lightly patterned pine wood or thick MDF are the most likely candidates. Each of these materials and others will be put through preliminary testing in order to find one that works best with the RFID antennae.

On the topic of RFID antennae, the electronics that are presently intended for use in the project are a Raspberry Pi module, the RC522 RFID reader and any other accompanying standard components such as breadboards and wiring. However, to ensure that these components are appropriate for the project, they must first be tested. These tests could yield disappointing results, requiring for components to be swapped out. The consequences of such are discussed in Section 5.3.1. Do note that this will not impact the chosen technology implementation of RFID, only the specific component choice, should it occur.

### 3.1.3 Web Host Development

While the prior stage establishes a physical prototype, the desired solution of this project cannot be achieved by this alone. A web application must support the back-end data management of the finished product. This requirement is established in Section 1.2. The essential portion of this stage is to create a web application capable of taking positional piece data, and updating a game environment accordingly. The functionality to identify pieces as per specific icons or images is also essential.

### 3.1.4 User-Informed Evaluation

In order to determine if the project has been able to successfully implement a physical online tabletop experience, a significant user evaluation stage is required. Specific enquiries, with a variety of participants will provide essential feedback and advice for improving the prototype design. From this data, one can create a second conceptual design and reinforce the intended user-informed evaluation stated in Section 1.2. The precise nature of the user evaluation stage is detailed in Section 6.1. Knowledge gained from my study of the Human-Computer Interaction module has provided sufficient insight into how this can be done effectively.

## 3.2 Secondary Tasks

The following section outlines tasks which lie beyond the essential scope of this project but may be explored given sufficient time.

Additional development of the web application would allow for a more fully-fledged and presentable finished product. For example, an inviting interface and additional functionality, such as pre-programmed animations and sounds based on game states. However, these features may require considerable web development skills, which I do not presently possess. Furthermore, this kind of web application development does nothing to improve standard functionality of the solution, and does not serve to fulfil any standard objectives.

While the end-goal of the project is to see an online game using the prototype in action, this would by nature require two prototype interfaces. Therefore, this task lies just beyond the scope of the project. However, in order to prove the functionality of online cooperative gameplay, simulation of the additional player's action can be present.

### 3.3 Requirements Specification

The investigation and setup of a functional sensory sub-system is a significant task and imperative for determining the parameters of the subsequent software development. The following is the summary of mandatory and optional project requirements:

| **Mandatory Requirements** | **Justification** |
|---|---|
| Background use case research on tabletop role-playing games | In order to create a prototype which serves its purpose effectively, sufficient knowledge on similar implementations and the scope of the use should be obtained beforehand. |
| Sensory technology research and comparison | In order to produce an appropriately functional prototype, the most fitting technology and electronic components should be realised beforehand. |
| Sensor technology testing to ensure adequate reading capabilities | Sensor components should be capable of reading through a range of thin materials at a range of a few centimetres, thus confirming their suitability for the prototype. |
| Prototype casing material testing to ensure structural soundness, heat resistance and non-conductivity | The casing material used for the prototype must undergo internal investigation to ensure it is will maintain its structure, will not present a fire hazard if surrounding basic electronic components and will not conduct electrical signals that could otherwise damage components or present an electrocution hazard. |
| Creation of sensor array capable of multiple simultaneous location recognition per second | A functional prototype must be made and presented to test participants in order to confirm research findings. In order to reflect the desire to create an interactive device for tabletop games it should be capable of reading multiple pieces in different locations, at a rate that results in close to real-time reflection in the prototype. Said array will be encased by a physical game board. |
| Functionality testing and critical reflection of prototype | Internal testing of basic functionality must be carried out to ensure that both the prototype and supporting code are functional so that the user testing stage is able to collect useful data. At this stage, the effectiveness, in terms of meeting the project objectives of the prototype will also be determined internally. This will be detailed in a critical reflection section. |
| Web application development to host a basic game | Gameplay functionality will be non-existent without a supporting web application to enable the flow of said game. Website should be capable of dynamically updating and reflecting actions made on the physical board in close to real-time performance. |
| User Testing and Feedback | The degree of success of the prototype solutions can only be judged effectively through user testing and feedback, from which one can improve and iterate the design and fulfil the user-informed evaluation. |
| Conceptualisation of second iteration of prototype | To further show that a key stage of the project is user-informed evaluation, it must be shown how the knowledge gained from internal tests and user feedback have been taken on. This will be done through designing a conceptual second prototype. |

Table 1: Table of mandatory requirements which this project aims to complete and document

| Optional Requirements |
| --- |
| Advanced web application development with additional gameplay features. |
| Creation, or partial creation of the conceptual prototype. |
| Creation of an additional prototype to facilitate a real online game. |

Table 2: Table of optional requirements which are extensions that lie beyond the scope of the project

# 4 Professional Considerations & Ethics

## 4.1 User Testing Compliance

This project meets all the specified requirements in the User Testing Compliance Form attached in Appendices 10.2, as follows:

- **Participants will not be exposed to any risk greater than those encountered their normal working life:** This user testing environment will not expose participants to any greater physical, mental or emotional harm than they would otherwise encounter going about their lives as normal.
- **The study materials are a mixture of paper-based and software running on standard hardware:** All electronic components in use are purchasable on typical and reputable marketplaces, and run well-known, standard software.
- **All participants must explicitly state that they agree to take part, and that they are comfortable with their data being used in the project:** A consent form outlining use of data will be provided to all participants.
- **No incentives will be offered to any participant:** Those who take part must do so purely out of their own good will, as to not be encouraged to risk themselves for greater incentives.
- **No information about the evaluation or materials will be intentionally withheld from any participants:** This test has no reason to deceive or mislead participants and will actively attempt to convey all necessary information to participants beforehand.
- **No participant will be under the age of 18:** No children or young people will be subjected to this test.
- **No participant with any disability or impairment that could limit their understanding, communication or capacity to consent will take part in the test:** No participants with disabilities or impairments will be subjected to this test.
- **Neither I nor my supervisor will be in a position of authority or influence over any participants:** Participants will not be pressured to take part or remain in this test by myself or my supervisor.
- **All participants will be informed that they have the right to withdraw from the test at any point:** The participants will be informed before the test begins that they are able to withdraw without question at any point if they would like to do so.
- **All participants will be informed of the contact details of myself and my supervisor:** These details will be provided before the test and participants will be provided with at least one copy of these details.
- **The evaluation will be described in detail to all participants at the start of the session, and participants will be fully debriefed at the end of the session. With all participants being given the opportunity to ask questions at either of these points:** Participants will be provided with sufficient information before the test is undertaken, and following the test, to ensure they understand the complete nature of the test.
- **All the data collected from the participants will be stored securely, in an anonymous form:** All data will be stored in an anonymous format on the university's OneDrive. This data will also be deleted one the project has concluded.

No members of the public aside from the project author, and its supervisor, Ronald Grau will or have been involved in the project. The undertakings of this project pose no threat to the health, privacy or wellbeing of its conductors, test participants nor the test environments. The hardware and materials in use are a mixture of common household electronics and basic construction materials, that would be typically found in mass-produced and hand-made goods. The hardware and materials intended for use in this project are detailed in Section 3.1.2. Test participants will only be expected to interact with a simple game board prototype and will not be required to touch any active electronic components. Furthermore, the components in question will not be storing any of the personal data of project conductors or test participants. Hence, no form of discrimination, malpractice or endangerment can occur against individuals conducting or participating within tests. Participants' health, privacy and wellbeing will not be at any greater risk than they otherwise would be during their normal working lives.

## 4.2 The Chartered Institute for IT Code of Conduct & Ethical Considerations

This project's testing procedure will also correspond with the BCS (The Chartered Institute for IT) Code of Conduct [2], as follows:

- **One must have due regard for public health, privacy, security and wellbeing of others and the environment:** This is supported through the aforementioned environment conditions, use of data and conformity with the User Testing Compliance Form.
- **One must conduct their professional activities without discrimination on the grounds of sex, sexual orientation, marital status, nationality, colour, race, ethnic origin, religion, age or disability, or of any other condition or requirement:** No discrimination of test participants will take place, and all those who conform to the additional requirements outlined in the User Testing Compliance Form are welcome to participate.
- **One must only undertake to do work or provide a service that is within their professional competence:** The user test stage will not commence until I have completed the relevant content in my Human-Computer Interaction module, to ensure that I am fully competent and experienced beforehand.
- **One must respect and value alternative viewpoints and, seek, accept and offer honest criticisms of work:** The project's user-informed evaluation requires that sufficient information is extracted from the user testing stage, in order to be realised. Hence, the aim of this testing stage is to take on as much advice from participants as possible.
- **One must reject and will not make any offer of bribery or unethical inducement:** Incentives offered by participants will never be accepted under any circumstances at risk of the project's findings being compromised. Neither I nor my supervisor will provide additional incentives for participants at risk of their wellbeing or honesty.

All other work tackled by this project already lies within areas of expertise that I am confident in. These skills have been provided by my Computer Science with Artificial Intelligence undergraduate degree and Electronics A-Level qualification. These skills and knowledge will be further improved through the undertaking of this project, provided that the objectives are completed, and that I am able to take on sufficient advice and insight from my supervisor. Criticism and advice from the project supervisor will always be considered with the highest degree of importance, as it could serve to ensure the productivity and safety of the project among countless other qualities.

Based on the knowledge that this project and its testing procedure both fully conform with both the User Testing Compliance Form and BCS Code of Conduct, my supervisor and I agree that an additional ethical review from the university will not be required.

# 5 Development

This section details the development process of the prototype device, creation of a physical board (comprised of a casing and accompanying electronics), web-based interface and subsequent critical reflection. The challenges faced at each stage are discussed, including how some issues required limiting the scope of the prototype, albeit still achieving the objectives outlined in Section 1.2, and meeting the Requirements Specification's mandatory requirements 3.3. To summarise, a prototype system was created by arranging a grid of sixteen RFID sensors, connected to a Raspberry Pi capable of sending positional data to a web-based server, housed in a wooden casing.

## 5.1 Project Management

Communication between myself and the project supervisor has been through email and the use of Trello. This is a professional project management tool that assists in formulation of project plans. It can help to prioritise and track tasks, while helping keep people who are working on a project 'in the loop'. Figure 7 depicts the associated project 'board' on Trello, which enables organisation of tasks into categories based on their progress. Comments can be added to 'cards' representing tasks or project stages, which allows for exchanging of questions and keeping up to date on project progress. File attachments can also be made to share drafts, while reminder and tagging features can be used to notify project members via email.

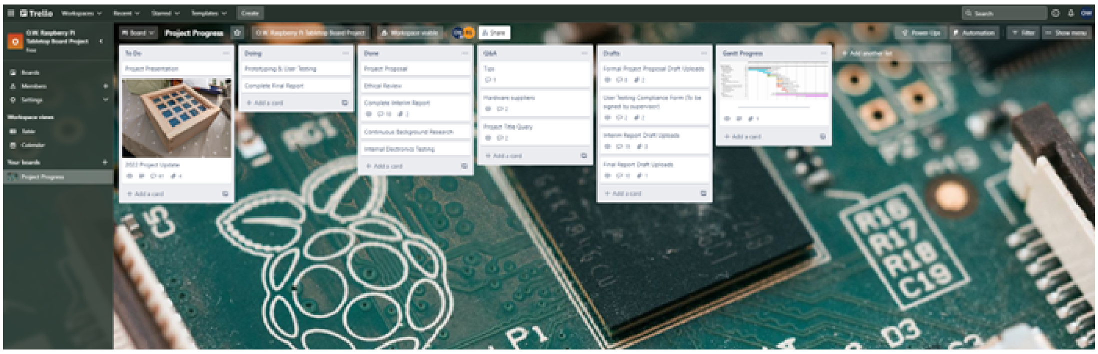


Figure 7: State of Trello board on the 6$^{\text{th}}$ of August 2022

## 5.2 Integrating Previous Work

The electronic portion of the prototype was based in part on previous work by Mark Hooper and Burack Ozter in their project: rfgrid - An Interactive RFID Display [31]. Express permission was obtained from Hooper to use the electronic circuitry from the rfgrid in this project. Hooper and Ozter's project was more ambitious in terms of physical scope and realisation than this one, indicated by their use of a great number of sensors and dedicated on-board game environments. This project produces a prototype that is significantly different from rfgrid. This is achieved through the integration of a physical board and web-based interface. This will permit adaptable play experiences and the ability for remote players to share a game, a feature not offered by rfgrid.

## 5.3 Internal Electronics

With Hooper supplying insight and schematics into the electronics, only minor alterations were necessary to create the circuit design. Figure 8 shows the circuit diagram of the prototype and Figure 9 is an image of said circuitry realised.

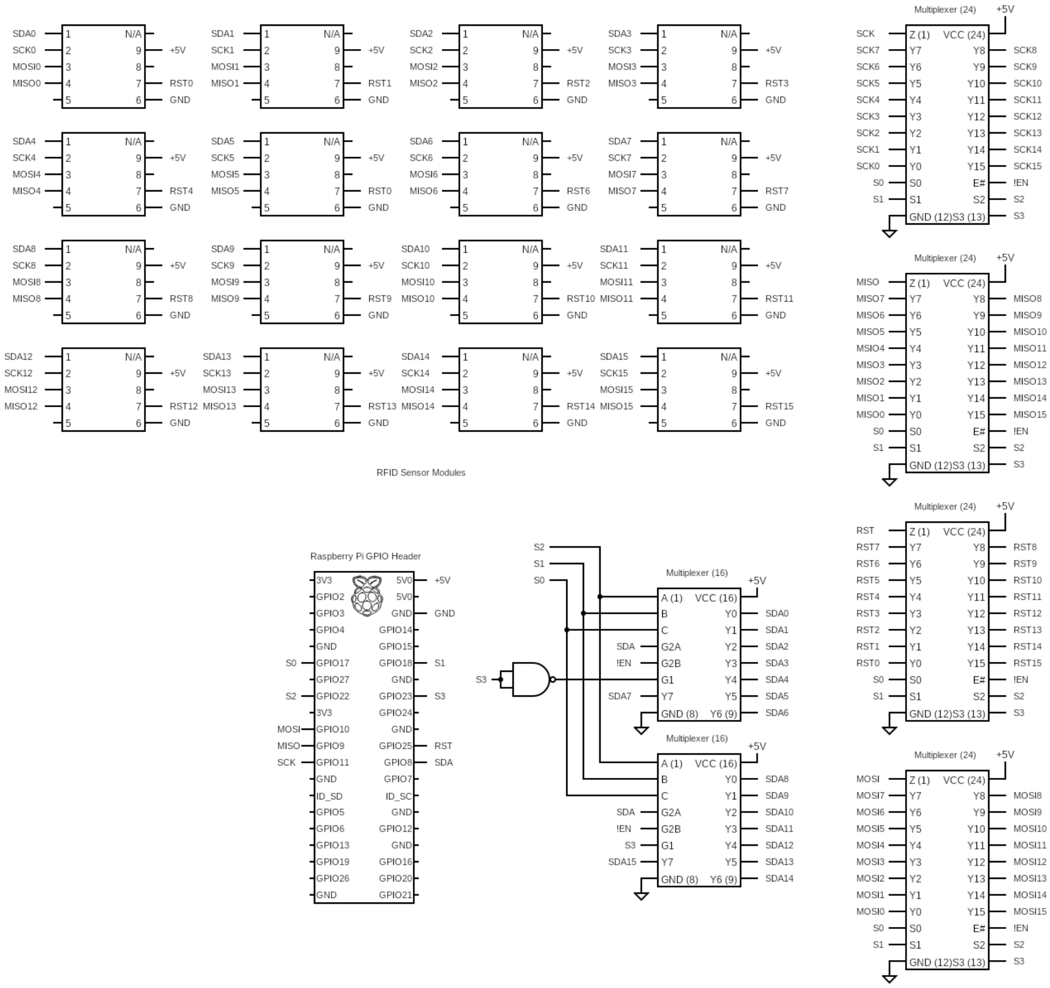


Figure 8: Circuit diagram of Interactive Tabletop Game Board prototype, based on schematics of rfgrid project [31]

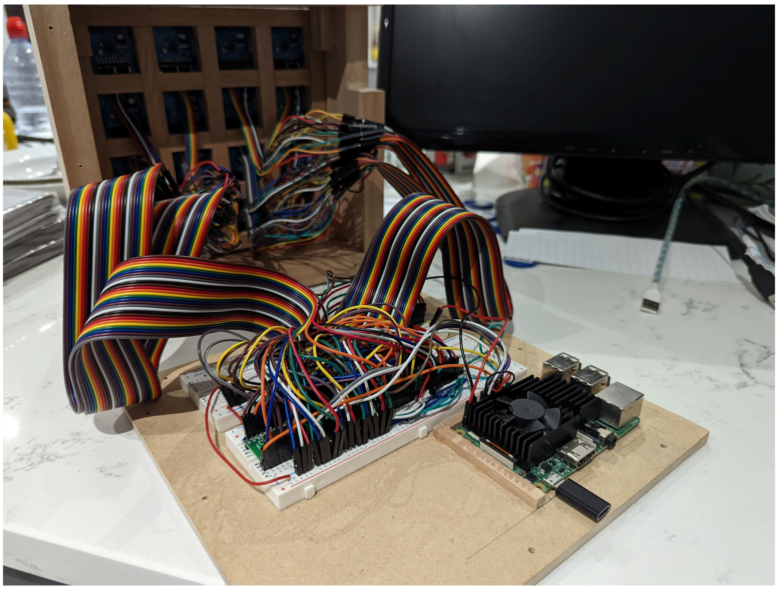

Figure 9: Image of internal electronics of prototype inside casing

The prototype was assembled on a pair of breadboards, using jumper wires to connect components. The list of said components is as follows:

- Sixteen RFID Sensor Modules: RobotDyn MFRC522 Reader/Writer Modules [10]
- One Raspberry Pi 3
- Four 24 Pin Multiplexer ICs: 74HC4067D Multiplexer/Demultiplexer [7]
- Two 16 Pin Multiplexer ICs: SN74F138DG4 Decorder/Demultiplexer [17]
- One NAND IC: M74VHC1G132DTT1G Logic IC [6]

### 5.3.1 Sensitivity Testing

Prior to assembling the prototype completely, it was necessary to test that the sensors were individually capable of reading tags from a sufficient distance, at a variety of angles. In the event that the detection spaces of sensors crossed over once the prototype was assembled, such detection spaces could be 'imaginary' locations for pieces on the board. The simple diagram in Figure 10 depicts how these 'crossover' domains could be utilised with a grid arrangement of sensors.

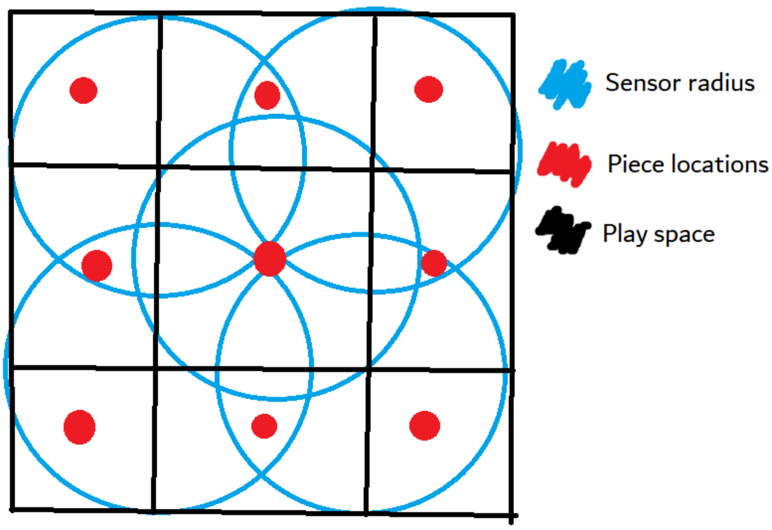


Figure 10: Diagram illustrating how overlapping detection radii can be used to obtain piece location data in a defined grid space

In the example depicted in Figure 10, it would only be necessary to use five sensors to read nine potential 'read zones'. This would be very beneficial for reducing costs in larger systems as RFID modules are not inexpensive components. For the prototype, sixteen sensors were purchased, which under these conditions would result in a minimum of twenty-five read zones. It would turn out that this would not be possible for us, which is elaborated on in Sections 5.3.2 and 5.6.

### 5.3.2 Internal Electronic Difficulties

Working with breadboards provides considerable flexibility when prototyping, however, some of the components where only available at the time of purchase in PCB-mounted packages. Hence, PCB adapter boards were obtained to use them. Additionally, the use of jumper wires was also intended to assist with flexibility, however, they ended up occupying more internal casing space than anticipated due to the number of connections required as per the circuit design.

The greatest difficulty encountered throughout the entire project was electromagnetic interference (EMI). EMI is unwanted noise or interference in an electrical path or circuit caused by an outside source. It is also known as radio frequency interference. EMI can cause electronics to operate poorly, malfunction or stop working completely [26]. A considerable amount of EMI was experienced in the prototype once the circuitry was fully assembled, resulting in degradation or loss of RFID sensor data.

It was not possible to attribute the EMI to any specific source without costly instruments, however, one can conclude that it was likely due to the dense arrangement of RFID sensors. Jumper wires can also create small amounts of interference if their connections are not tight enough. Similar 'muddying' of signals can also occur in solder-less breadboards and jumper wires due to the means in which they transmit signals relying entirely on sufficient contact of rigid materials.

This in turn creates further challenges and in the absence of incurring increased costs on use of higher quality components, modifying the prototype casing and considerable further testing, the presence of EMI was not something that could be realistically solved with the prototype. To lend credence to the speculation that the degradation or outright loss of electronic signals was due to EMI, it was observed that these issues were exacerbated when coupling more sensors to the circuit. For the purpose of the user testing stage, reasonable allowance was made for inoperable sensors.

## 5.4 Website & Raspberry Pi Programming

The site of the prototype was run using Apache [1] and built on Django [4], a Python-based web framework. Django was selected because it reduces the amount of code necessary to run a simple site and allows for very simple integration with a database back-end. I had also not used it before, so it provided for a good learning opportunity. The solution aimed to provide flexibility when it comes to display options. For example, the website can be viewed on a smart phone, or even projected atop the board portion of the prototype. This is an approach explored in Section 2.1 and utilised in the rfgrid project [31]. In the user testing, detailed in Section 6, the website was displayed on an accompanying monitor, as there was no access to a projector.

This section also covers integration between the website and the internal electronics, thus facilitating gameplay. This is achieved through Python scripts run on the Raspberry Pi module, which monitor physical board states and send information to a website database. The benefit of using Python in both the scripts and website is that integration between the two is seamless, allowing for all game logic and AI to be handled by the Raspberry Pi, further generalising and simplifying the web interface design. Figure 11 describes the general flow of looping processes which allow the prototype system to function, with the green events handled by the Raspberry Pi scripts, and the blue events handled by the website.

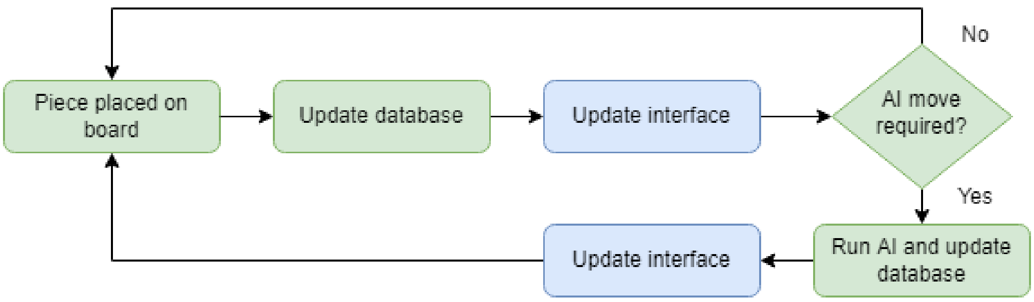


Figure 11: Flowchart of prototype system's gameplay loop

Little difficulty was experienced during this website construction stage of development, particularly in comparison to the electronics stage. I had sufficient background knowledge on web development and hosting going into the project, so exploring the use of Django and dynamic pages was adequately challenging and educational, while not hindering the prototype development progress.

### 5.4.1 Website Architecture

As previously mentioned, the site was run using Apache and built on Django. The back-end of the website was built using a fair amount of the advice from a PiMyLifeUp tutorial [23]. Said back-end also includes a simple database, which stores data on pieces, their identities, positional data and their respective Unique Identifier (UID) data. The benefit of this is that the positional data of pieces can be changed by anything than can update the database. In the case of the prototype, this means the Raspberry Pi and a mobile phone with administrator access to the site can both update positional data. The code for the website (and Raspberry Pi) is accessible from the project's GitHub repository [36].

Django enforces a Model-View-Template (MVT) architecture, comprised of three such key elements [33]. Models are the interface of data and responsible for maintaining said data, typically represented by a back-end database. In the case of this project, an SQLite [14] database was used to maintain the data of the piece locations on the board. Views are the user interface, represented by a combination of HTML, JavaScript and CSS files in the case of this project. Finally, templates are slightly more nuanced, as they contain statics parts of the HTML and special syntax to describe some processes. With this project, the templates along with JavaScript enable dynamic data uploads and displays. Apps, not included in the acronym, are essentially Django's version of 'projects' or collections of files that make up a site.

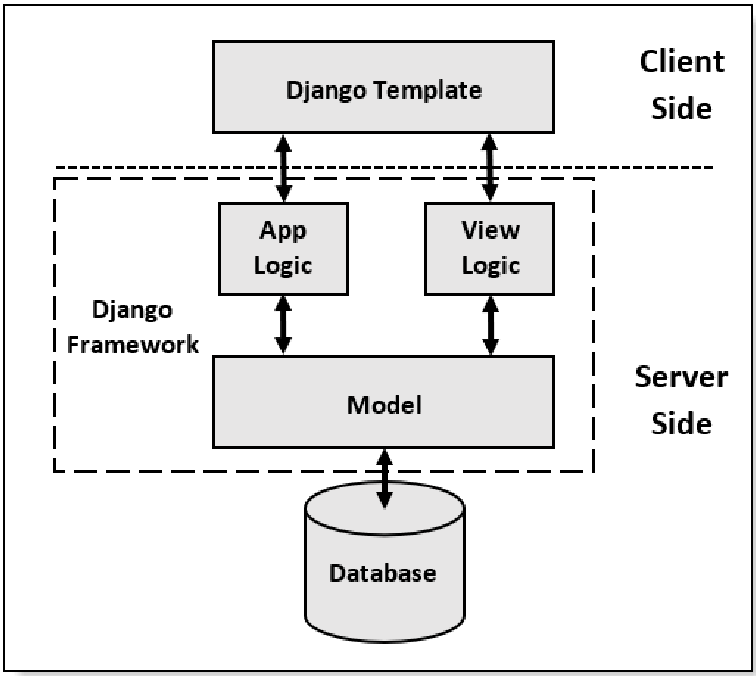


Figure 12: Depiction of Django framework architecture [34]

### 5.4.2 Website Interface Design

In order to guarantee that the site would be unobtrusive, a very simple interface would be most suitable for the user testing. This way, one can likely obtain more explorative advice on how users would like the interface to look. Figures 13 and 14 show screenshots of the web interface provided to users. Note how the grid has been reduced to a three by three to accommodate for the sensor issues discussed in Section 5.3.2.

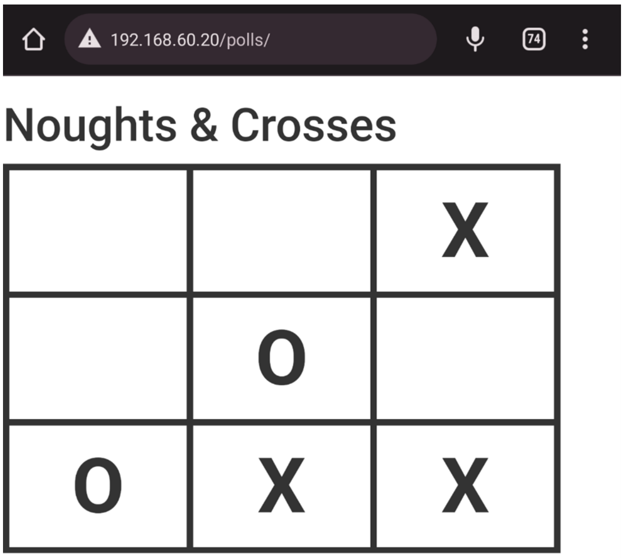


Figure 13: Screenshot of the user interface provided for a game of noughts and crosses


Figure 14: Screenshot of the user interface provided for a 'role-playing'-type game

The front-end of the site was built with the assistance of a tutorial on the Django site [18]. The web pages shown in Figures 13 and 14 update dynamically according to the back-end database, providing a close to real-time reflection between web interface and board. From the internal testing of the system and the user testing, it was found that the web page typically updated in under three seconds of placing a piece on the physical board.

```
<script>
  document.addEventListener("DOMContentLoaded", () =>
  {
    setInterval(function()
    {
      fetch("{% url 'polls:getBoardState' %}").then(res => res.json().then(json =>
      {
        console.log(json);
        const item = document.querySelector("#display");
        while (item.firstChild)
        {
          item.removeChild(item.firstChild);
        }
        const currentCords = [];
        for(var key in json.cords) {
          for(var key1 in json.cords[key]) {
            if (typeof json.cords[key][key1] === 'string')
            {
              currentCords.push(json.cords[key][key1]);
            }
          }
        }
        CODE TO CREATE TABLE ELEMENT FROM PIECE DATA
      })).catch(res =>
      {
        console.log(res);
      });
    },1000);
  })
</script>
```

Listing 1: HTML script to produce grid from database's piece positional data

Listing 1 shows a reduced section of the code which facilitates the dynamic grid of the website. It constantly creates and updates a table element according with the positional piece data reported by a JSON (JavaScript Object Notation) response, containing the relevant piece coordinates. The code describing the creation of the table is extensive and non-essential for this depiction, so has been replaced by a note. It is within this noted code that conditionals are included to determine what the 'icon' of a particular piece is, based on the JSON data. To ensure the site runs without issue, the script is run once every second.

### 5.4.3 Raspberry Pi Programming

The Python scripts running on the Raspberry Pi are responsible for monitoring the state of the physical board. Two Python libraries that were used in this code are worth particular mention, those being the MFRC522 [8] and sqlite3 [15] libraries. The former of which allows interaction with the RFID readers. Listing 2 contains the code which makes up the primary loop in the scripts. One may note the use of the MFRC522 library functions, allowing interaction with the RFID readers once their addresses are determined by the GPIO.setup() calls. Following this, simple logic and a 'double check' validate any tags that are picked up by the reader, before adding the relevant coordinates and UIDs to a list representation of the board's state.

```
try:
  num_moves = 0                 # MAX NUMBER OF AI MOVES COUNTER
  while (True):
    board_state_temp = []
    for i in range(9):          # CHECK EVERY SENSOR IN ADDRESS LOOP
      GPIO.setmode(GPIO.BOARD)
      GPIO.setwarnings(False)
      GPIO.setup(11, GPIO.OUT)
      GPIO.setup(12, GPIO.OUT)
      GPIO.setup(15, GPIO.OUT)
      GPIO.setup(16, GPIO.OUT)
      GPIO.output(11, S0_cycle[i])
      GPIO.output(12, S1_cycle[i])
      GPIO.output(15, S2_cycle[i])
      GPIO.output(16, S3_cycle[i])
      reader = MFRC522.MFRC522()
      (status, TagType) = reader.MFRC522_Request(reader.PICC_REQIDL)
      (status, uid) = reader.MFRC522_Anticoll()
      if len(uid) == 5:
        if uid[0] == 51 or uid[0] == 83 or uid[0] == 99
            or uid[0] == 227 or uid[0] == 243:
          reader.MFRC522_SelectTag(uid)
          board_state_temp.append(tuple((i, uid)))
        else:
          board_state_temp.append(tuple((i, none)))
      else:
        board_state_temp.append(tuple((i, none)))
      reader.Close_MFRC522()
    board_state_temp.sort(key=lambda tup: tup[0])
    board_state.sort(key=lambda tup: tup[0])
    # IF BOARD STATE HAS CHANGED, DOUBLE CHECK THEN UPDATE DATABASE
    if board_state != board_state_temp:
      for index, t in enumerate(board_state_temp):
        if board_state[index] != board_state_temp[index]:
          GPIO.setmode(GPIO.BOARD)
          GPIO.setwarnings(False)
          GPIO.setup(11, GPIO.OUT)
          GPIO.setup(12, GPIO.OUT)
          GPIO.setup(15, GPIO.OUT)
          GPIO.setup(16, GPIO.OUT)
          GPIO.output(11, S0_cycle[index])
          GPIO.output(12, S1_cycle[index])
          GPIO.output(15, S2_cycle[index])
          GPIO.output(16, S3_cycle[index])
          reader = MFRC522.MFRC522()
          (status, TagType) = reader.MFRC522_Request(reader.PICC_REQIDL)
          (status, uid) = reader.MFRC522_Anticoll()
          if len(uid) != 5:
            uid = none
          temp_find = tuple((index, uid))
          if board_state_temp[index] != temp_find:
            board_state_temp[index] = board_state[index]
      board_state = board_state_temp
      result = decode_cords(board_state)
      send_data(result, num_moves)
except KeyboardInterrupt:
  print ('QUIT')
  GPIO.cleanup()
```

Listing 2: Main loop code from Raspberry Pi script

Following the main loop of code, in the instance of the board state changing, the database therefore needs updating. The sqlite3 library allows for seamless interaction in this project. Provided that the script can reference the file path of the database, the database can be interacted with directly in the Python script. Listing 3 shows how the database can be interacted with to update existing records. One will also notice that the sqlite3 library allows uses of any sqlite function, though in this case only UPDATE and SELECT are used.

```
# SEND PLAYER MOVE TO DATABASE
def send_data(state, num_moves):
    dbase = sqlite3.connect('db.sqlite3')
    cur = dbase.cursor()
    for pair in state:
        cord = pair[0]
        piece = pair[1]
        if cord not in fixed:
            if piece != 0:
                query = "UPDATE polls_cord SET XyCords = ? WHERE PieceId = ?"
                cur.execute(query, (cord, piece))
            else:
                query = "SELECT * FROM polls_cord WHERE XyCords = ?"
                for row in cur.execute(query, [cord]):
                    if row[1] == 'player0':
                        query = "UPDATE polls_cord SET XyCords='none' WHERE PieceId = ?"
                        cur.execute(query, [row[2]])
    dbase.commit()
    dbase.close()
    comp_move(state, num_moves)
```

Listing 3: Code which updates database after player moves from Raspberry Pi script

The Rasperry Pi scripts enable simple intraction between the physical board and website, tying the prototype system together comfortably. Once again, facilitating such communication was imperative to make the prototype work, and distinguish its purposes and proofs on concept separate from the rfgrid project. These scripts also include the code necessary to calculate AI moves, which recursively search potential moves within a game, searching for the 'best' move it can make, a Minimax algorithm. In the case of the games implemented in this project, AI was only necessary for noughts and crosses. The particular implementation of AI in this case, prioritised moves that only benefited the computer opponent offensively. Thus, the computer would rarely make moves that intentionally blocked its opponent, making for more enjoyable games during testing.

### 5.5 Prototype Casing

A casing would be necessary to house the electronics of the prototype. It was decided to make a simple box out of wood, with the option of a clear plastic top that can sit on top of the sensors. My Grandfather assisted in the construction of the casing.

### 5.5.1 Design

Figure 15: Prototype casing

Figure 15 depicts the casing. It was designed with the intent of appearing similar to traditional tabletop game boards, hence the wooden build. Though there are warm electronics housed inside the casing, there should be no risk of fire. Precautions such as limited voltages and attentive connection of wires will prevent components from getting too hot. The Raspberry Pi was also equipped with an active cooler fan, to keep CPU and subsequently module temperatures low. Internal testing yielded that no components exceeded 30 degrees Celsius under load. Most woods will not start to burn until reaching roughly 160 degrees Celsius, meaning the prototype is completely safe.

### 5.5.2 Prototype Casing Difficulties

Maintaining a resemblance of a traditional tabletop game board was important, as to reinforce intuitive thinking among study participants during testing. So, keeping the casing size to a minimum, particularly in terms of depth was important to us. This did however, mean that space for jumper wires internally was reduced, resulting in tight margins of error for wire placement and increased risk of EMI (as discussed in Section 5.3.2).

Retaining symmetry in the casing also required sacrifice of easy access to the connectors of one row of the RFID sensors, as said connectors were accessible from only one side of the sensor modules. It would have been possible to reconfigure the connectors, such that they face downwards and would then be more easily accessed internally. This however, would require disconnecting and replacing every connector on each module. A process that could have jeopardised the signal integrity of the sensor array even more as the connectors would then be relying on my solder quality instead of their more precise existing solder joints.

## 5.6 Critical Reflection of Prototype

This section will reflect on the shortcomings of the prototype, as assessed internally during development. Firstly, the most significant flaw of the prototype is its susceptibility to EMI. There are two likely culprits of this issue: power and reader collision. The sixteen sensors are sharing a 5V supply, so all the sensors are operating on a voltage lower than this. The sensors were receiving sufficient power, as they were all intermittently functional and showed positive power indicators. However, there is no guarantee that the sensors will function as fully intended when running on lower voltages than rated. To counter this, the sensors were connected via their 3.5V positive supply connections.

RFID reader collision is a more difficult problem to solve. Reader collision occurs when the signals from two or more readers overlap and the tag is unable to respond to simultaneous queries [16]. This is a challenging problem to solve in the context of the system, because the typical approach is to ensure that only one reader within a group is active at a time. However, in this project's system, introducing downtime to any sensors will reduce responsiveness and potentially worsen the user experience. The second approach is a more extensive validation process for readers. RFID is a somewhat notorious for how inconsistent it can be without proper reading validation, sometimes referred to as RFID middle-ware. The prototype's code employs the use of a 'double-check' process for tags. It double-checks tags that are detected but has no protocol for situations where tags aren't detected. I have not personally enquired with Hooper as to how his project [31] successfully avoided this issue as of the writing of this report. As such, the approach this project suggests, detailed in Section 8, involves the creation of custom RFID antennae. To summarise, this would potentially have the effect of reducing the specificity of reader range, thus reducing the chance of reader crossover significantly. The aforementioned section also explains how this can be done alongside increased power supply.

Despite this issue reducing the scope of the prototype, the project has still achieved the objectives outlined in Section 1.2. A general-purpose game board has been produced, capable of tracking pieces and displaying game states, changing them in real-time, in response to physical interaction. While the game environments and playing pieces in the rudimentary website integration are very simple, they provide proof that so long as there is a database back-end in communication with a dynamic web page, the system needs only to be optimised electronically to fully realise the motivated intentions of creating a tabletop product capable of bringing people together, despite being so far apart in today's world.

# 6 User Testing & Feedback

This section details the user testing and feedback results obtained from test participants. This stage also informed the final evaluation of the prototype and subsequent second prototype concept detailed in Sections 6.6 and 8 respectively.

## 6.1 Methodology Outline

The approach adopted in this project to obtain user feedback through testing, was an observational study based on a cognitive walkthrough. Participants of the study were given tasks designed to test specific and general aspects of the prototype. During these tasks, observations of the user and prototype behaviour were noted. After the tasks, users were given a questionnaire designed to encourage constructive criticism of the prototype. The hope going into this stage of the project, was that users would provide insight into the shortcomings of the prototype that were not noticed during internal testing or evaluation of the prototype.

## 6.2 Outline of Tasks

The first task presented to the participants was play a game of noughts and crosses against myself on the physical board. In this task, users were shown the interface display but it was not entirely necessary to complete the task, as all the pieces necessary to determine the state of the game were on the physical board. The intent behind this task was to introduce the physical board to the user and identify behaviour patterns when it came to using the board. For example, seeing if users would make an attempt to press the sensors as if they were buttons, or remove the RFID tag 'pieces' once they had been placed. This task would essentially determine if a user would able to use the physical board portion of the prototype without assistance, allowing one to ascertain whether or not the board has a sense of intuitive design about it.

The second task was to play a game of noughts and crosses against the computer. This task requires the participant to use the interface display. Its purpose was to identify if users were able to associate the interface with the board and understand that the interface is a representation of the board's state. This task also provided opportunity to see if the AI opponent algorithm was suitable in this case. Figure 13 depicts the interface users were given during this task. Where the first task was a general test of how participants found using the physical board, this task is a general test of the display interface. Though, this task also acts as the first test of the aforementioned AI and system responsiveness as perceived by the user.

The third task was to make an illegal move against the computer in the noughts and crosses game. The purpose of this task was two-fold, in determining were truly able to infer the state of a given game through the interface, and how the AI would react to illegal moves. While the prior task simply asks the user to play against the computer, it does not require the user to actually understand the state of the game through the interface. This task instead forces the user to infer what would constitute an illegal move, given the current game state, something that can only be done by observing and understanding the display interface. In this case, users are once again presented with Figure 13 and are instructed to play first as the 'noughts' player. In the event the user makes a legal move, it could suggest that the interface does not make itself a clear representation of the board.

The fourth task was to move one space at a time, from a given starting position, towards the goal in the role-playing game. At this stage, participants were presented with the interface illustrated in Figure 14. The goal of this task was to test the adaptability of the displayed interface. While interface's simplicity does not lend to an attractive experience, I believe its strength is in its adaptability. The necessary components to test the display across different display mediums were not available at the time of testing, however, the general versatility of the interface can still be evaluated. Through observing the users during this task, one could discern through user behaviour and speed of actions, if the new game interface was easily interpreted by the users. Fluid usage without much hesitation would suggest that the users had no trouble understanding this new game. The foundation of the interface would remain unchanged, thus implying that the interface's foundational design lends itself to adaptability. If the inverse occurred and users had trouble making the change to the new game, it might suggest the interface's simplicity is a detriment to its adaptability, lacking the context required for users to move from game to game with the same interface from a structural perspective.

The final task was to make an illegal move in the role-playing game. The purpose of this task was similar to task three, in that it was to infer if users were able to identify certain elements of the interface. An illegal move could constitute one or a combination of two things, given the context of this game's rule provided in task four. To make an illegal move, the user could either move more than one space in a single move, move into one of the black 'inaccessible' spaces or both. If a user was to move into one of the black spaces, this would demonstrate that they understand, through the user interface, that these spaces are not supposed to be accessed. On the other hand, if the user were to only move more than one space, it could suggest that the user interface was not clear enough in expressing the inaccessibility of the black spaces, thus not making them clear illegal moves. Though it should be noted that if a user does not move to a black space, it can not be said with certainty that they did so out of not recognising the nature of these spaces. The summarised goal of this task is to reveal the nature of participants' understanding of this game, presented through the displayed interface's illustrations.

## 6.3 Participants

Participant selection for the user testing and feedback stage would require some of the contextual understanding derived from the research detailed in Section 2.1. While it is challenging to pin down a demographic for TTRPGs in general, one can obtain some numbers after specifying to a degree. In the case of this user testing and feedback stage, skewing demographic research in the direction of what motivated me to undertake this project would be most appropriate, that being Dungeons & Dragons and online RPG settings. While there is no consensus on the key demographic this project is looking for [11] [22], it would appear that the predominant group is roughly 18-35 years old, with a mostly male identifying but generally mixed range of genders. Selected participants would also have experience in either table-top role-playing games or board games in general, as it would suggest that they were more suited to providing feedback concerning the prototype as opposed to the game presented, which were not expressly being tested in comparison to the system in which they were played on.

I can say this is personally reflective of the people I've played with. Hence, it was an appropriate target group for user testing participants to align with. The five participants selected were a mixture of family members and fellow students that all fell within the desired demographic specifications outlined prior.

## 6.4 Task Findings

The following section compiles findings from observations made during the cognitive walkthrough tasks presented to study participants.

During the first task, some users expressed or exhibited trouble placing and aligning pieces. This was an issue that lied with the RFID tags provided during testing, which were sized and shaped like large coins, with the exceptional qualities of having a protruding segment on one edge for hanging onto key chains and lacking completely flat faces. The selection of these tags as playing pieces was an oversight, which will have a conceptual solution provided in Section 8. During this task, some users also had trouble recognising the connection between the board and screen interface. It is believed this issue is rooted mainly in a lack of visual connection between the physical board and interface.

Observations made during the second task include users making very frequent visual checks between the physical board and displayed interface, occasionally looking at the display while interacting with the tags on the board. The precise reasoning behind this behaviour cannot be discerned without further insight from the relevant users, though speculations can be made. One could assume this behaviour is an indication of the system's disconnection between board and display, resulting in the users desiring to confirm their actions repeatedly instead of relying on the prototype to translate their actions accurately. To lend credence to this assumption, an additional observation made during this task was that of faster movements made by users, occasionally too fast for the system to reflect their action on the display before the user would make an attempt to start their next action. While the behaviour in each of these groups of participants suggests they exhibited significantly different degrees of comfort with the prototype at this stage, they both indicate that the responsiveness of the system, a parameter highlighted for testing in this task, was lacking in this case. The AI performance in this task was also sufficient but predictable. As a result of the sensor inaccuracies discussed in Section 5.3.2 some nonoperational sensors were given predefined states, creating a partially completed noughts and crosses 'puzzle' for users to start from. This limited the number of locations the AI could reasonably select, however, it never made illegal moves and also only selected spaces that provided offensive benefit, the intended behaviour outlined in Section 5.4.3.

From the third task, it was observed that a small handful of users asked for clarification on what constituted an illegal move, then easily made the move once it was clarified that an illegal noughts and crosses move was desired. At this stage, it is believed all participants understood the state of the game through the interface, thus allowing them to infer what was required of them to make an illegal move. This suggests that after some experience in using the system, the displayed interface is clearly recognised as a representation of the current board state. A particularly important finding, as it reaffirms the completion of this project's objective to make a prototype which can display game environments and playing pieces on a website, such that gameplay is facilitated, as this task's observations would suggest that the users understood the confines of the game they were playing. With regards to the AI behaviour in this task, it was observed that the AI would continue to play as normal after the player made an illegal move, behaviour that's not desirable if one doesn't know the rules of the game.

With the fourth task, faults concerning the interface were observed. Some users asked for clarification as to what the 'goal' was. Several users were not able to recognise that the black spaces on the interface were inaccessible 'wall' spaces. Other users failed to move only one space at a time. All of these findings generally suggest that the interface's simplicity is a detriment to its adaptability. In attempting to create a user interface that can be applied to a wide range of TTRPG settings, an interface which lacks the ability to clearly present what it is showing in some cases has resulted. This issue will be discussed in greater length in Sections 6.6 and 8.

Finally, the only notable observation made during the fifth task was that all participants succeeded in making an illegal move, with only one participant opting to not do so through placing a piece in one of the black spaces. This suggests that in this case, the interface was sufficient in illustrating what would constitute an illegal move. However, findings from the observations during the fourth task conflict with this, reasonably implying that there are separate intuitive and lacking aspects of the interface. Although, behaviour exhibited in this task specifically suggests that the use of black spaces in the context of the project's simple RPG game were sufficient in communicating their 'inaccessibility' to almost all players.

## 6.5 Questionnaire Findings

The following section compiles findings extracted from the questionnaire that followed the cognitive walkthrough portion of the user testing and feedback stage.

Firstly, positive feedback will be detailed to confirm the successes of the prototype. Participants expressed that they tended to find the board intuitive and easy to use, often citing this experience to its simplicity. Those who initially did not recognise the connection between the board and screen interface said that they found interaction easier once this was explained to them. While there was a general consensus that the screen interface was less engaging, the majority of participants expressed that they found it self-explanatory and easy to interpret. From all this positive feedback, it can be determined that the prototype was relatively sound, at least from a foundational perspective, an opinion also held by myself prior to the user testing stage.

The negative feedback was extensive so is detailed in brevity. Users expressed their displeasure with the RFID tag pieces, explaining that they were difficult align and place onto the sensors due mostly to their shape. This in tandem with inconsistent and low responsiveness from the sensors and system at large resulted in a poor experience with regards to interaction with the prototype. Similarly, users stated that they felt a disconnect between the board and separate display, with most participants expressing that they found the interface unappealing, or that their attention was not drawn to it. Some participants were concerned that the board would be difficult to see if dark environments due to the lack of built-in lighting. The same absence of lighting, along with other visual or auditory stimuli, was a concern for users who said there was a lack of exciting or engaging features that would've retained their attention for longer.

Other elements of feedback from the questionnaire include some direct suggestions of improvement. Firstly, a magnetic board allowing for easy piece alignment. Provided that the magnets don't interfere with the sensors, this would also reduce RFID reading issues by keeping pieces in precise locations. Secondly, a storage place for the playing pieces. Third, haptic feedback such as vibration motors to reinforce good or bad actions while playing. This suggestion not only combats issues observed from this stage's tasks regarding the system's reliance on the user to understand the rule of the game they're playing, but also adds a physical and auditory stimulation to the board, something which was highlighted in this section's negative feedback. Fourth, some users wanted to see a "sleeker" or "flatter" design that would better resemble a modern tabletop game board. Fifth, one user suggested the introduction of a 'turn switch' to indicate which player's turn it currently was. This would not only make the turn state clearer to the user but could also act as a very simple means of validation for the Raspberry Pi to identify if it should be looking for player movements or making AI movements. Finally, one user had a very creative suggestion of approaching the system from a more social perspective, by having a much larger board that could facilitate multiple games at different points on said board. This is a considerable departure from the scope of this project, however, I believe it to be a natural evolution of the ideas explored in this project. Especially considering this user's mention of the project's RPG inspiration sprouting this idea.

## 6.6 Prototype Evaluation

Through compiling the findings in Sections 5.6, 6.4 and 6.5, an evaluation of the prototype can take place.

It should be stressed firstly that the prototype does meet the objectives outlined in Section 1.2 as follows; with a board that facilitates a means of tracking pieces, while displaying game states on an accompanying interface. The interface reflects changes in the physical board state in real-time through a dynamic website which handles the visuals attributed with the physical pieces and context of the game (which is determined by the bespoke game scripts run on the Raspberry Pi module). Furthermore, user feedback expressed that most test participants found the prototype usable and self-explanatory, and that they had an immediate understanding of how to use the device in most of the tasks. Several users also expressed their appreciation of the simplicity in both the physical board and web interface providing an unobtrusive and intuitive experience.

While the web interface is simple, user feedback confirms that this is both a benefit and drawback to the system, allowing for an intuitive and self-explanatory interface, at the cost of an absence of engaging visuals. However, some HTML wizardry and a more advanced understanding of interface design is all that stands in front of improving this particular issue, a procedure colloquially referred to as the 'interface-lift'. With several users suggesting animations and "fancy graphics", it is clear that many improvements can be made to this interface.

Furthermore, the clearest issue with the prototype presently is the sensor array inconsistency, detailed in Section 5.3.2. Recognised as a persistent and serious problem during both development and the user testing stage, while this issue does limit the consistent operation of the prototype, it doesn't wholly cease functionality, ensuring that the project has still met its goals. Providing a fix for this issue is a nuanced endeavour detailed in Section 8.

The prototype has also mistakenly disregarded concern for the RFID tags, an issue made particularly present during user testing. Future iterations of this project should pay attention to these tags and the means by which they interact with the board. Physically appealing designs, with magnetic connection to the board and storage space are just a handful of improvements that could be made.

With regards to users indicating the lack of attention grasping features, this is an issue which requires tackling on several fronts. The 'interface-lift' mentioned earlier in this section would do some heavy lifting in this department but isn't all that's required. Introducing lights, speakers and vibration motors to provide practical benefits and stimuli would be the first engagement improvements made to the physical board. While the project sought to facilitate physical interaction over online gameplay, it does not encourage it, due in part to a lack of stimuli in the board.

Reduction of the board's size and elevating its design language is key to presenting it as an appealing device for users. The most important dimension of the board which could use reduction would be its height, that being the direction in which it extends up from whatever surface it is placed on. Additionally, the use of plastic in place of wood might sacrifice the traditional appearance aimed for in Section 5.5 but would provide structural benefits and greater internal arrangement adaptability, a desirable quality to improve electronic stability. On a similar note, allowing for more boards to be connected adjacently would not only satisfy the intent to make the system scalable, but also introduce potential for the 'social gaming' experience mentioned at the end of Section 6.5.

To summarise, the shortcomings of the prototype are as follows:

- Lack of consistently operational sensors due to EMI
- Non-intuitive pieces and piece placement methods
- Lack of stimuli in game board
- Unappealing web interface
- Relatively bulky game board
- Design is not scalable

# 7 Conclusion

In conclusion, this project has achieved the base objectives it set out to accomplish. An interactive board was made, which can be used as a general-purpose tabletop game board, capable of tracking pieces and reflecting corresponding 'game states' on a display. The displayed interface, while rudimentary, can show game environments and playing pieces, proving that in future iterations of this project, more advanced HTML and Javascript would greatly elevate the final product.

The other mandatory requirements (specified in Section 3.3) have also been achieved. Background use case and sensory technology research was carried out and detailed in Section 2, while all other mandatory requirements involving the development or testing of parts from either the physical board or website are all detailed in Section 5. The requirements to undertake a user testing stage and produce a conceptual second iteration of the prototype are also realised in Sections 6 and 8 respectively. Said sections also allowed for the realisation of this project's objective to have a user-informed evaluation. Furthermore, the second prototype concept greatly improves on the current device.While the development of this prototype lies beyond the scope of this project, it would make for significantly educational future work.

The challenges met over the course of this project include many hurdles both small and large with regards to the internal electronics. While the consequences of some of these challenges remain, it was through the persistent action and support of the project supervisor and I that these flaws did not hinder the project's ability to conclude successfully. The same can be said for other general issues such as mistakes in time management, which were rectified through the use of communication and planning, as described in Section 5.1.

In achieving all this, a greater understanding of the development required to produce these kinds of devices has been acquired. As a result of this project, I also now understand nuanced electronics topics surrounding RFID technology, such as reader collision and the impacts of EMI. I would once again like to thank all those mentioned within the Acknowledgements for assistance during this project, and those who take the time to read it.

# 8 Future Work

This section aims to address the shortcomings outlined in Section 6.6 through suggestions and concepts of potential future prototype.

The most important flaw to overcome is our lacking sensor array, a problem which can be solved by using less advanced technology. During background research on RFID solutions, it was discovered it's not unusual for individuals to make their own antennas for reading RFID signals. These DIY antennas are usually made of a coiled wire made of materials such as copper. This often results in lower range and lower accuracy readers, but when done properly, can lead to readers with bespoke and specific detection spaces, in a low-profile format. Utilising sensors with very specific detection spaces will result in far less risk of reader collision, which providing proper EMI insulation, will result in retained RFID signals.

On the topic of changes to the board, adding LED lights and small haptic motors to each antenna location is the next desirable. They will be optionally activated when pieces are placed in their physical or online locations. A small speaker will also be added to the side of the casing, to similarly play sounds under certain game conditions. It should be noted these lights and motors will be secured above the antennas, but underneath a thin translucent plastic top, such that the approximate locations of sensors are still barely visible even without the lights.

Magnets will also be mounted above each sensor. These will secure the pieces atop the plastic, providing the user with a more certain and satisfying means of placement. It is important to assure that these magnets are passive and persistent, not electromagnets. The latter of which is capable of damaging the internals of the device and even the passive RFID tags.

It should be noted that these tags are also in need of redesign. The 'puck' shape is still desirable, as it allows for easy storage and manoeuvrability across the board. However, making the tag completely circular, and come with thin Velcro (or similar securing methods) to attach tabletop game pieces atop them. As for a storage method, a small box which one can attach to the side of the board via clips should be sufficient. This way no internal space of the board is sacrificed, while still providing a convenient location to hold pieces.

The final intention with regard to the board is to make it sleek and scalable. To do this, the use of a plastic casing, a single multiplexed reader to sixteen antennae, PCB internals, a 'turn-switch', rechargeable batteries and 'hotswap' sockets/plugs to connect to other board modules. All of these elements in combination, result in a device which is smaller, lighter, scalable, portable and more reliable. A breakdown of what each design decision does for the concept is as follows:

**Plastic Casing & PCB Internals:**

While detracting from the familiar tabletop board aesthetic of wood, plastic allows for a greater degree of control over the internal design of the casing, including supporting structures of plastic inside the mould. Plastic will also reduce the weight of the board, while lending itself to the 'sleeker' design. Furthermore, by using a PCB to connect the components, one can greatly reduce the internal footprint of said components, as compared with the current solution, which crams lots of wiring into a tight space.

**Multiplexed Reader:**

Multiplexing a single reader between sixteen antennae will mean that only one reader module is needed for the same amount of coverage achieved by the first prototype. This should reduce the power draw of the device and total cost of components.

**'Turn-swap' Button:**

A turn swap button is the last line of defence when it comes to validating piece movement. As per the nature of RFID systems, readers will always be slightly less consistent than desired, so use of a physical determiner of who's turn it is will go a long way in improving the responsiveness of the system.

**Rechargeable Batteries:**

Use of batteries will improve the prototype on several fronts. Firstly, the power constraints of the Raspberry Pi module will now be less of a problem, as the power supplied to the RFID modules, LEDs, speakers and haptic motors can be done via batteries instead. This inclusion also lends itself to making the device more portable, while still allowing the option for wired power via a charging port.

**'Hot-swap' Sockets & Plugs:**

Sockets and plugs located on three of the four edges of the board will allow for the device to cover a considerably greater number of spaces. The processing load from the RFID readers can be distributed between separate Raspberry Pi modules, which in itself would require the Pi modules to handle such allocation. However, with the reduced complexity of using less RFID readers, it would not be necessary for each device to even have a Raspberry Pi, further reducing cost and increasing scalability.

Finally, the refinement of the website interface. The department of advanced web and UI design is beyond the expertise of myself, so substantial elaborations, or conceptualisations will not be provided in this section. One can however, say that designing the interface with the express intent of primarily displaying it via projector on top of the game board would be most appropriate. This would help to reduce the 'disconnect' some users experienced during our study and is better facilitated by our new translucent plastic top, while also providing a workaround to the concerns expressed by some user testing participants that the challenging to use in dark environments. A rendering of our resulting concept is provided below in Figure 16.

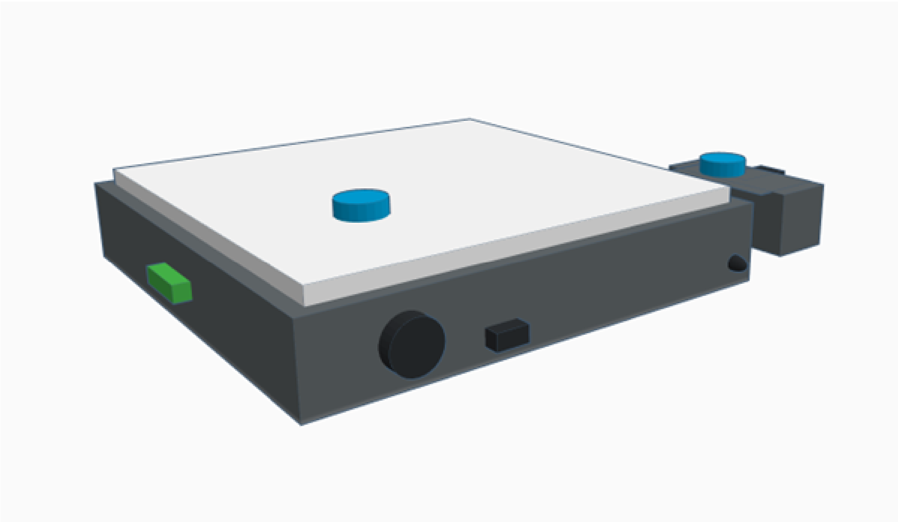

Figure 16: 3D render of concept second prototype

The desire to explore the 'social gaming' idea presented during the user feedback should also be noted, as it seems like a natural progression of the device. This however, seems like such a departure from the original motivations of the project, that it lies beyond the scope of this report. I believe the exploration of this idea would make for a considerably interesting separate project in the future.

# 9 References


[1] The apache software foundation. https://www.apache.org/. Accessed: 15th April 2022.

[2] Bcs code of conduct | bcs. https://www.bcs.org/membership/become-a-member/bcs-code-of-conduct/. Accessed: 6th November 2021.

[3] Dgt board. https://www.chessprogramming.org/DGT_Board. Accessed: 15th September 2021.

[4] Django | the web frame work for perfectionist with deadlines. https://www.djangoproject.com/. Accessed: 15th April 2022.

[5] K&j magnetics, inc. - reed switches and hall effect sensors. https://www.kjmagnetics.com/blog.asp?p=reed-switches-and-hall-effect-sensors. Accessed: 17th September 2021.

[6] M74vhc1g132dtt1g onsemi, logic ic, nand gate, single | farnell. https://uk.farnell.com/on-semiconductor/m74vhc1g132dtt1g/nand-gate-single-5sot-23/dp/2101846?ICID=I-RP-STM7REC-1. Accessed: 27th October 2021.

[7] Nexperia 74hc4067d,652 multiplexer/demultiplexer single 16:1 5 v, 24-pin soic. https://uk.rs-online.com/web/p/multiplexer-demultiplexer-ics/4836566/. Accessed: 27th October 2021.

[8] pimylifeup/mfrc522-python: Library utilized for pi my life up's guide on setting up an rfid rc522 reader. https://github.com/pimylifeup/MFRC522-python. Accessed: 9th March 2022.

[9] Rfid buying guide - barcodes edge. https://www.barcodesinc.com/barcodesedge/guides/choosing-the-right-rfid-technology/. Accessed: 21st September 2021.

[10] Robotdyn rfid reader/writer, nfc module, mfrc522. https://robotdyn.com/rfid-reader-writer-nfc-module-mfrc522.html. Accessed: 26th October 2021.

[11] Role playing and strategy games: User demographics. https://www.aarki.com/insights/role-playing-and-strategy-games-user-demographics. Accessed: 4th June 2022.

[12] Roll20: Online virtual tabletop for pen and paper rpgs and board games. https://roll20.net/welcome. Accessed: 10th September 2021.

[13] Sony xperia touch - android powered touch projector - video project (us warranty). https://www.amazon.com/Sony-Xperia-Touch-Projector-Warranty/dp/B074Q58NY5. Accessed: 5th November 2021.

[14] Sqlite. https://www.sqlite.org/index.html. Accessed: 15th April 2022.

[15] sqlite3 — db-api 2.0 interface for sqlite databases. https://docs.python.org/3/library/sqlite3.html. Accessed: 21st April 2022.

[16] Technical problems with rfid. http://www.technovelgy.com/ct/Technology-Article.asp?ArtNum=20. Accessed: 10th May 2022.

[17] Texas instruments sn74f138d, decoder, 16-pin soic. https://uk.rs-online.com/web/p/encoder-decoder-ics/0526600/. Accessed: 27th October 2021.

[18] Writing your first django app. https://docs.djangoproject.com/en/3.1/intro/tutorial01/. Accessed: 16th April 2022.

[19] Xperia touch - overview - xperia touch - sony developer world. https://developer.sony.com/develop/xperia-touch/. Accessed: 5th November 2021.

[20] Open-source electronic chessboard with bluetooth. http://talkchess.com/forum3/viewtopic.php?f=2&t=57902, 2015. Accessed: 16th September 2021.

[21] B. Bulsink. Device for detecting playing pieces on a board, 1998. US6168158B1.

[22] Hoffer C. Forty percent of dungeons & dragons players are 25 or younger. https://comicbook.com/gaming/news/dungeons-and-dragons-demographics-2020/. Accessed: 4th June 2022.

[23] Emmet. Installing django on your raspberry pi. https://pimylifeup.com/raspberry-pi-django/. Accessed: 15th April 2022.

[24] Victor Feria. Rfid chess video. https://www.youtube.com/watch?v=TDM3AOoncOo, 2018. Accessed: 20th September 2021.

[25] S. Garrido-Jurado, R. Muñoz-Salinas, F.J. Madrid-Cuevas, and M.J. Marín-Jiménez. Automatic generation and detection of highly reliable fiducial markers under occlusion. *Pattern Recognition*, 47(6):2280–2292, 2014. URL: https://www.sciencedirect.com/science/article/pii/S0031320314000235.

[26] Wright Gavin. electromagnetic interference (emi). https://www.techtarget.com/searchmobilecomputing/definition/electromagnetic-interference. Accessed: 29th May 2022.

[27] R. Hiller. Turn your table top into an interactive display with the touchjet pond. https://geekdad.com/2017/04/touchjet-pond/, 2017. Accessed: 9th September 2021.

[28] S. Hinske and M. Langheinrich. An rfid-based infrastructure for automatically determining the position and orientation of game objects in tabletop games. *Concepts and Technologies for Pervasive Games-A Reader for Pervasive Gaming Research*, 1, 2007. URL: https://www.semanticscholar.org/paper/An-RFID-based-Infrastructure-for-Automatically-the-Hinske-Langheinrich/b141ccef79499428aaaa4b21fe9daa106b1d8165.

[29] E. Huang and N. Shen. Interactive blitz chess: A physical blitz chess board powered with pic32. http://people.ece.cornell.edu/land/courses/ece4760/FinalProjects/f2015/eh549_nds64/eh549_nds64/eh549_nds64/eh549_nds64.html, 2015. Accessed: 16th September 2021.

[30] Bruce Land. Chess board - magnetic sensing. https://www.youtube.com/watch?v=VhKgAz2PJWU, 2016. Accessed: 16th September 2021.

[31] Hooper M. and Ozter B. rfgrid - an interactive rfid display. https://github.com/markdhooper/rfgrid-ECED4900. Accessed: 25th October 2021.

[32] C.J. Martinez, K. Seggerman, and A. Perez. Observing hand placement and measurement on a tabletop using a depth camera. *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction*, 2015. URL: https://dl.acm.org/doi/10.1145/2677199.2687904, doi:10.1145/2677199.2687904.

[33] Arora N. Django project mvt structure. https://www.geeksforgeeks.org/django-project-mvt-structure/. Accessed: 3rd August 2022.

[34] Big Nige. Mastering django: Structure. https://djangobook.com/django-tutorials/mastering-django-structure/. Accessed: 3rd August 2022.

[35] F. Nilsson and Polner A. An object tracking system for a tabletop board game. 2019. URL: https://www.diva-portal.org/smash/get/diva2:1480697/FULLTEXT01.pdf.

[36] Wright O. Interactive-tabletop-game-board. https://github.com/Marmite-Pyjamas/Interactive-Tabletop-Game-Board. Accessed: 31st July 2022.

[37] Vishal V. Pande, Pooja D. Doifode, Dhanashree S. Kamtekar, and P. Shingade. Wireless power transmission using resonance inductive coupling prof. 2014. URL: https://www.semanticscholar.org/paper/Wireless-Power-Transmission-Using-Resonance-Prof-Pande-Doifode/75c30b27d9f29e685ee932b96129fa7bc9153c8e#paper-header.

[38] R. Sodhi. Dungeons & dragons and settlers of catan with projeciton mapping. http://projection-mapping.org/dungeons-dragons-projection-mapping/, 2015. Accessed: 10th September 2021.

[39] N. Statt. Sony's prototype projector turns any tabletop into a touch-sensitive display. https://www.theverge.com/2016/3/13/11215454/sony-interactive-projector-future-lab-sxsw-2016, 2016. Accessed: 9th September 2021.

# 10 Appendices

## 10.1 Project Meeting Log

**September 7$^{\text{th}}$ 2021:**
Ronald and I shared our first online meeting where we discussed the aims and inspiration behind my project. Risks of the project such as taking on too much unfamiliar territory was covered as was the suggestion to investigate sensory approaches.

**September 16$^{\text{th}}$ 2021:**
Ronald and I shared our second online meeting where I updated Ronald on the success of my research and expressed my intention of pursuing a particular approach for prototyping.

**September 29$^{\text{th}}$ 2021:**
Ronald and I shared our first in-person meeting where we discussed any new findings in my research and the importance of putting together some prototype designs, such that a list of required components could be put forward.

**October 27$^{\text{th}}$ 2021:**
Ronald and I had our second in-person meeting where we discussed my progress on finalising a parts list for our first prototype, such that we could proceed in getting hold of the necessary hardware. Ronald pointed me to a handful of websites I could use to look at the cost of the desired RFID sensors, and I followed up the meeting by letting him know what I intended to order over the weekend. We also spoke about how the project's evaluation stage would require interaction with willing test participants. The project met all of the points found in the User Testing Compliance Form, and as such would not require an ethical review.

**December 8$^{\text{th}}$ 2021:**
Third online meeting, where Ronald and I reviewed the current project state and wished each other well over Christmas. At this point I had all the parts necessary to do component testing over the break and work on further expanding the report.

**February 7$^{\text{th}}$ 2022:**
Third in-person meeting, where Ronald and I caught up with project progress over the break. Not too much progress was made beyond the testing of components and some expansion to the report, but I made it clear to Ronald that I had a sense of direction and committed to at least having schematics for the prototype within a month's time.

**March 14$^{\text{th}}$ 2022:**
Fourth in-person meeting, work on the prototype could finally begin as schematics and a parts list were ready. I presented Ronald with the list and we discussed the prospects of funding, as the RFID sensors required were slightly expensive. Despite not having an outcome on funding at this stage, Ronald and I agreed I should order the parts now and worry about that later, such that development could get underway.

**April 27$^{\text{th}}$ 2022:**
Fifth in-person meeting, I updated Ronald on some personal life issues I was experiencing at the time, which were severely impacting my ability to work on the project. Ronald suggested that I take time for myself and do what work I can, and instructed me to stay in close communication with him and other support avenues within the university.

**May 9$^{\text{th}}$ 2022:**
Sixth in-person meeting, I expressed to Ronald that my present issues were not improving at the rate I had hoped, whilst encountering further EMI issues with the prototype. Ronald suggested that the best course of action may be to postpone the project until the exam resit period in August, a suggestion I agreed with, as it would allow me more time to recover both my own issues and those of the prototype.

**July 24$^{\text{th}}$ to August 7$^{\text{th}}$ 2022:**
Ronald and I exchanged continuous communication over this period, in which we discussed improvements to the final report given the state of the prototype. Over this time, Ronald provided insight into rectifying the project most appropriately and resulted in a report we were both happy with.

## 10.2 User Testing Compliance Form

# User Testing Compliance Form for UG and PGT Projects*
# School of Engineering and Informatics
# University of Sussex

This form should be used in conjunction with the document entitled "Research Ethics Guidance for UG and PGT Projects".

Prior to conducting your project, you and your supervisor will have discussed the ethical implications of your research. If it was determined that your proposed project would comply with **all** of the points in this form, then both you and your supervisor should complete and sign the form on page 3, and submit the signed copy with your final project report/dissertation.

If this is not the case, you should refer back to the "Research Ethics Guidance for UG and PGT Projects" document for further guidance.

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1. Participants were not exposed to any risks greater than those encountered in their normal working life.
   *Investigators have a responsibility to protect participants from physical, mental and emotional harm during the investigation. The risk of harm must be no greater than in ordinary life. Areas of potential risk that require ethical approval include, but are not limited to, investigations that require participant mobility (e.g. walking, running, use of public transport), unusual or repetitive activity or movement, physical hazards or discomfort, emotional distress, use of sensory deprivation (e.g. ear plugs or blindfolds), sensitive topics (e.g. sexual activity, drug use, political behaviour, ethnicity) or those which might induce discomfort, stress or anxiety (e.g. violent video games), bright or flashing lights, loud or disorienting noises, smell, taste, vibration, or force feedback.*

2. The study materials were paper-based, or comprised software running on standard hardware.
   *Participants should not be exposed to any risks associated with the use of non-standard equipment: anything other than pen-and-paper, standard PCs, mobile phones, and tablet computers is considered non-standard.*

3. All participants explicitly stated that they agreed to take part, and that their data could be used in the project.
   *Participants cannot take part in the study without their knowledge or consent (i.e. no covert observation). Covert observation, deception or withholding information are deemed to be high risk and require ethical approval through the relevant C-REC.*

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*This checklist was originally developed by Professor Steven Brewster at the University of Glasgow, and modified by Dr Judith Good for use at the University of Sussex with his permission.

*If the results of the evaluation are likely to be used beyond the term of the project (for example, the software is to be deployed, the data is to be published or there are future secondary uses of the data), then it will be necessary to obtain signed consent from each participant. Otherwise, verbal consent is sufficient, and should be explicitly requested in the introductory script (see Appendix 1).*

4. No incentives were offered to the participants.
   *The payment of participants must not be used to induce them to risk harm beyond that which they risk without payment in their normal lifestyle. People volunteering to participate in research may be compensated financially e.g. for reasonable travel expenses. Payments made to individuals must not be so large as to induce individuals to risk harm beyond that which they would usually undertake.*

5. No information about the evaluation or materials was intentionally withheld from the participants.
   *Withholding information from participants or misleading them is unacceptable without justifiable reasons for doing so. Any projects requiring deception (for example, only telling participants of the true purpose of the study afterwards so as not to influence their behaviour) are deemed high risk and require approval from the relevant C-REC.*

6. No participant was under the age of 18.
   *Any studies involving children or young people are deemed to be high risk and require ethical approval through the relevant C-REC.*

7. No participant had a disability or impairment that may have limited their understanding or communication or capacity to consent.
   *Projects involving participants with disabilities are deemed to be high risk and require ethical approval from the relevant C-REC.*

8. Neither I nor my supervisor are in a position of authority or influence over any of the participants.
   *A position of authority or influence over any participant must not be allowed to pressurise participants to take part in, or remain in, any study.*

9. All participants were informed that they could withdraw at any time.
   *All participants have the right to withdraw at any time during the investigation. They should be told this in the introductory script (see Appendix 1).*

10. All participants have been informed of my contact details, and the contact details of my supervisor.
    *All participants must be able to contact the investigator and/or the supervisor after the investigation. They should be given contact details for both student and supervisor as part of the debriefing.*

11. The evaluation was described in detail with all of the participants at the beginning of the session, and participants were fully debriefed at the end of the session. All participants were given the opportunity to ask questions at both the beginning and end of the session.

    *Participants must be provided with sufficient information prior to starting the session, and in the debriefing, to enable them to understand the nature of the investigation.*

12. All the data collected from the participants is stored securely, and in an anonymous form.

    *All participant data (hard-copy and soft-copy) should be stored securely (i.e. locked filing cabinets for hard copy, password protected computer for electronic data), and in an anonymised form.*

**Project title:** Raspberry Pi-Based Interactive Tabletop Game Board ___________________

**Student's Name:** Oscar Wright___________________________________________________

**Student's Registration Number:** 201774__________________________________________

**Student's Signature:** OSCAR WRIGHT_____________________________________________

**Date:** 4th November 2021_______________________________________________________

**Supervisor's Name: _____Ron Grau_________________________________________**

**Supervisor's Signature: ______R Grau_ (electronically)________________________**

**Date: ______4/11/21_________________________________________________**

### 10.3 Project Proposal

# Final Project Proposal

Candidate Number: 201774

Project Supervisor: Ronald R. Grau

## Raspberry Pi Based Interactive Tabletop Game Board

**Aims**:

- To develop and protype an interactive board which could be used as a general-purpose tabletop game board. The development and evaluation of this prototype should reflect a user-centred design process.
- To facilitate a means to track pieces on such a board, so that additional effects can take place under user-defined game states.

The motivation for undertaking this project stems from my experiences with online tabletop gameplay and its inherent lack of physical and tangible interactions with a game board and other players. This project aims to create a device which will help alleviate the aforementioned qualities which are absent from a tabletop game experience when playing online.

**Objectives**:

Primary Objectives:

- To research differing means of tracking tabletop game pieces and identify the most appropriate approach to be used in prototyping. This research should investigate solutions based in computer vision, magnetic sensors, frequency sensors and others. The purpose of this research stage is to find at least one appropriate candidate for prototype implementation. Similar projects and products will be explored in detail.
- To create a functional, proof of concept game board prototype that enables piece tracking that can be communicated to a Raspberry Pi. The most appropriate approach found during the research stage will be implemented in the first prototype. The goal of this stage is to confirm that the findings from research can produce a working solution, which should be improved and iterated upon.
- To perform user experience testing to identify the shortcomings of the prototype, in order to design a series of other potential solutions. The produced prototype should be put through multiple user testing stages to establish where improvements can be made. If necessary, these findings will require the creation of a new prototype, which will undergo the same testing, and so forth. This will enforce the user-centred design process of the project.

Extensions:

- To develop a web application to be used in tandem with the board prototype which would change the ‘environment’ of the game board depending on the game state reported by the Raspberry Pi.
- To create two functional game boards that both connect to the web application, to facilitate and play an online game.

**Relevance**:

This project relates to my degree course in the following ways: It will provide me the opportunity to perform research into a specific case of human-computer interaction being that of interactive board games. It will also allow the chance to express my software and hardware development skills as I will be working with the Raspberry Pi platform, the relevant programming languages, and physical electronics to create a prototype.

**Resources Required**:

**Personal Weekly Timetable**:

| | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday |
|---|---|---|---|---|---|---|---|
| 9:00 | | | K&R Lecture | K&R Lecture | | | |
| 10:00 | | | | | | | |
| 11:00 | | | CompSec Lab | | | | |
| 12:00 | | | | | Project Lecture | | |
| 13:00 | CompSec Lecture | | | | | | |
| 14:00 | K&R Lab | | | | CompSec Lecture | | |
| 15:00 | | HCI Lecture | | | | | |
| 16:00 | | HCI Seminar | | Project Lecture | | | |
| 17:00 | | | | | | | |
| 18:00 | | | | | | | |

Yellow: Allocated one-hour sessions

Orange: Allocated two-hour sessions

Green: Time I will actively devote to this project (could include additional free time over weekends)

**Bibliography of Background Reading**:

Anderson, D. (2014) *Interactive Tabletop Project:ed*. Available at: https://github.com/daniel-andersen/interactive-tabletop-project-ed_old_iphone (Accessed: 10th September).

Bulsink, B. (1998) *Device for detecting playing pieces on a board*. US6168158.

*DGT Board*. Available at: https://www.chessprogramming.org/DGT_Board (Accessed: 15th September 2021).

Hiller, R. (2017) *Turn Your Table Top Into an Interactive Display with the Touchjet Pond*. Available at: https://geekdad.com/2017/04/touchjet-pond/ (Accessed: 9th September 2021).

Hinske, S. and Langheinrich, M. (2007) *An RFID-based Infrastructure for Automatically Determining the Position and Orientation of Game Objects in Tabletop Games*. Zurich: Institute for Pervasive

Computing. Available at: http://www.vs.inf.ethz.ch/publ/papers/hinske-pg07-rfidtabletop.pdf (Accessed: 25th September 2021).

Nilsson, F. and Polner, A. (2019) *An object tracking system for a tabletop board game. Malmö: Faculty of Technology and Society*. Available at: http://ls00012.mah.se/handle/2043/28786 (Accessed: 8th September 2021).

(2015) *Open-source electronic chessboard with Bluetooth*. Available at: http://talkchess.com/forum3/viewtopic.php?f=2&t=57902 (Accessed: 16th September).

Perez, A. and Seggerman, K. (2015) *Observing Hand Placement and Measurement on a Tabletop Using a Depth Camera*. Available at: https://dl.acm.org/doi/10.1145/2677199.2687904 (Accessed: 8th September 2021).

Sodhi, R. (2015) *Dungeons & Dragons and Settlers of Catan with Projection Mapping*. Available at: http://projection-mapping.org/dungeons-dragons-projection-mapping/ (Accessed: 10th September 2021).

Statt, N. (2016) *Sony's prototype projector turns any tabletop into a touch-sensitive display*. Available at: https://www.theverge.com/2016/3/13/11215454/sony-interactive-projector-future-lab-sxsw-2016 (Accessed: 9th September 2021).

**Interim Log**:

**September 7th**: Ronald and I shared our first online meeting where we discussed the aims and inspiration behind my project. Risks of the project such as taking on too much unfamiliar territory was covered as was the suggestion to investigate sensory approaches.

**September 16th**: Ronald and I shared our second online meeting where I updated Ronald on the success of my research and expressed my intention of pursuing a particular approach for prototyping.

**September 29th**: Ronald and I shared our first in-person meeting where we discussed any new findings in my research and the importance of putting together some prototype designs, such that a list of required components could be put forward.

## 10.4 User Testing Script

# User Testing Script:

**Introduction –**

Hello, today we are conducting a user experience study for our electronic board game prototype. We need participants to inform us on the quality of the prototype. You'll be asked to complete a series of simple tasks with the prototype and then answer some questions regarding your experience.

We'll be collecting observational data from your performance during the tasks and your answers during the questionnaire section. Please be reassured that the collected data will be securely stored in an anonymous format.

During the tasks, you will be able to ask me questions and seek limited guidance. However, I will not be able to tell you how to complete the tasks, as this will help inform us as to how intuitive the prototype is. Do note that these tasks are not a test of ability, we are testing the prototype, not yourself. Once you think you have completed a task, just let me know and we'll move onto the next one.

You are free to withdraw from the study at any time. Would you like to participate?

Thank you, do you have any further questions? As I may not be able to answer your questions during the tasks.

**Tasks –**

- Here we have a 3x3 game of noughts and crosses, please play as noughts against me.
- Please play again, but this time against the computer.
- Let's play against the computer again, but this time, perform an illegal move.
- Now we have a roleplaying game, please navigate your piece to the goal, moving one space at a time.
- Starting again, but this time, please perform another illegal move.

**Questions –**

- How did you find the general usability of the physical board?
- What about the usability of the computer interface?
- Any other specific elements that negatively impacted on your experience?
- Are there any features that you feel were missing from this prototype?
- Do you have any other questions or comments you'd like to ask or make regarding your experience?

**Debrief –**

The aim of today's study was to evaluate the user experience of our electronic board game prototype. In particular, we wanted to know how intuitive our mixed-media interface was for users.

Do you have any questions or comments about today's study?

Okay, here are the contact details of myself and my project supervisor, should you wish to contact either of us with further questions in the future. Thank you so much for participating in today's study.

## 10.5 User Experience Study Findings

# User Experience Study Findings

## Participant A –

### Task Observations –

**Task 1:**
Had trouble aligning tokens and sensors, made repeated attempts to slide tokens around when plastic top was in place.
**Task 2:**
Frequently looked between the board and screen, clarifying that they were struggling to understand where the opponent's pieces were.
**Task 3:**
No issues.
**Task 4:**
Asked for clarification on where the goal was, made an illegal move into a wall. Made a further illegal move by moving more than one space at a time. Said that they did not interpret the black spaces on the screen as walls.
**Task 5:**
No issues.

### Questionnaire Answers –

**Question 1:**
I didn't like how the pieces didn't fit in the slots properly, and the plastic sheet just made them slide around. Maybe a magnetic board would be better. It would also be better if the spaces lit up when I put things on them, or if the board was lit up in general so that it could be used in the dark.
**Question 2:**
It's annoying that the screen is separate from the board, it's also not a one-to-one representation between the screen and board, because not all the pieces from the screen are on the board, which is confusing.
**Question 3:**
I didn't like how the pieces didn't fit, maybe if there was also a sound that played when they're in the right place that would help.
**Question 4:**
A storage place for the tokens would be nice, I feel like they'd be easy to lose.
**Question 5:**
Haptic feedback like vibrations would also be nice.

## Participant B –

### Task Observations –

**Task 1:**
No issues.
**Task 2:**
Often made moves slightly too fast for sensors to react.
**Task 3:**
No issues.
**Task 4:**
Asked for clarification on where the goal was.
**Task 5:**
No issues.

### Questionnaire Answers –

**Question 1:**
I found it very usable. Made sense to me straight away without any extra explanation.
**Question 2:**
It made the game clear enough to me, but it is a little dull.
**Question 3:**
It didn't feel super responsive at times, so a speed improvement would be nice.
**Question 4:**

Maybe some noises like ‘beeps’ would make the whole thing more engaging.
**Question 5:**
What are the options for screens, does it have to be on this kind of monitor?
*Participant was informed that the screen interface can be displayed by anything with access to the website, such as phones or projectors.*
Oh, that’s very accessible, seems like something I might buy if it was faster and maybe in a sleeker package.

## Participant C –

### Task Observations –

**Task 1:**
Had trouble placing tokens in spaces, suggested during the task that they could be more “tactile”.
**Task 2:**
No issues.
**Task 3:**
No issues.
**Task 4:**
No issues.
**Task 5:**
No issues.

### Questionnaire Answers –

**Question 1:**
I found it logical, very self-explanatory and it has a clear layout. I prefer the smooth plastic on top because it feels more intentional and professional.
**Question 2:**
It’s just as simple as the board, but maybe that isn’t a good thing. Could do with some more colour and excitement.
**Question 3:**
The detection was not very responsive at times, I don’t know how you’d fix that, but it was the only practical problem I had with it.
**Question 4:**
It’s pretty simple and not too cluttered. Maybe some lights in the frame of the box or under each of the sensors. So that they can turn on in response to detecting something.
**Question 5:**
While I liked how effective and simple the screen was, it could do with some jazzing up, like graphics or animations.

## Participant D –

### Task Observations –

**Task 1:**
Took a moment to understand that the screen showed a representation of the board.
**Task 2:**
No issues.
**Task 3:**
No issues.
**Task 4:**
Did not recognise black spaces as walls (inaccessible spaces) straight away, correctly after realising the screen did not react to their placement on a wall space.
**Task 5:**
No issues.

### Questionnaire Answers –

**Question 1:**
I think it was very simple after I understood the box and the screen were basically the same thing.
**Question 2:**
Same thing really, but I did find it a little boring after a while because the screen is very plain.
**Question 3:**

I felt like the games were really simple and a little too easy. Maybe something like a timer would make it more difficult, or maybe a tougher game with more tiles.

**Question 4:**

You know how they have those switches in chess tournaments to flip between players' turns? Something like that would make it more obvious when it's my turn or the computer's.

**Question 5:**

I feel like if this was a much bigger board, you could make it into a social thing where you have people play multiple games at once in different places on the board. Just an idea but hearing the mention of RPG inspiration got me thinking about it.

## Participant E –

### Task Observations –

**Task 1:**

Had trouble understanding task. Required study conductor to step in and explain that the screen shows a representation of 'imaginary' pieces that are on the board.

**Task 2:**

No issues.

**Task 3:**

Required clarification that the illegal move had to made in the context of noughts and crosses rules.

**Task 4:**

No issues.

**Task 5:**

No issues.

### Questionnaire Answers –

**Question 1:**

I'd like it to feel more interactive. Maybe sounds and lights would go a long way. I felt my attention drifting at times so that's the kind of thing that could be helped with this or the screen.

**Question 2:**

Same deal. Maybe a home screen and a better sense of what the screen is showing me with context would be good.

**Question 3:**

The pieces didn't feel like they fit into the slots, and they slid around on the plastic, so different shapes or heavier pieces would be nice.

**Question 4:**

No features to the board I can think of. Maybe just some pizazz on the screen like animations or cooler icons for each piece.

**Question 5:**

Maybe if the board was flatter, would be a bit easier to move around and look more like a game board. I'd be interested in seeing future versions of this thing.