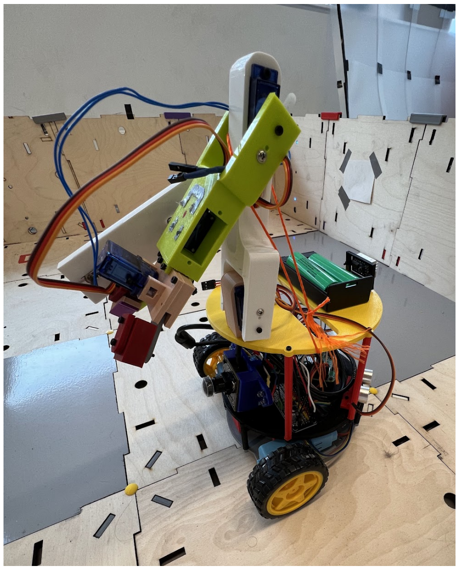
Robot Escape Room v2:

Repairbot F.I.S.H. and the Asteroids of Annihilation



A Major Qualifying Project Report submitted to the Faculty of the WORCESTER POLYTECHNIC INSTITUTE in partial fulfillment of the requirements for the Degree of Bachelor of Science

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DATE: April 27, 2023

Abstract

In this project our three major disciplines– Computer Science (CS), Interactive Media and Game Development (IMGD), and Robotics Engineering (RBE)– worked together to create an engaging robot escape room experience. Participants join the game via a website, where they are informed that they are in an asteroid field on a spaceship, and that they must fix the ship in order to escape the field and save the crew. The player is given access to the camera feed from F.I.S.H., the repairbot, via the website interface, through which they must navigate F.I.S.H. to solve a series of puzzles using the keyboard as controls. This not only tasks the player to think critically, but also demands versatility from the robotics and puzzle elements in order to make this a fun playing experience. The website links the room and robot together to create a seamless experience for the player using MQTT, with the room keeping track of the player's progress in regards to the puzzles and how the robot has acted as the physical manipulator of the room thus far. The project examines the combination of real world robotics engineering and the fantastical world of game design, all connected by the digital world of computer science.

Acknowledgements

We would like to thank our Advisors Berk Calli, Melissa Kagen, and Gillian Smith for their support and guidance during this project. We would also like to thank all of our playtesters for their feedback during the creation of this project, their insights were crucial. Finally we would like to thank the owners of Escape New Haven, Max Sutter and Ethan Rodriguez-Torrent, for their input and knowledge of traditional escape rooms. We could not have completed this project without the help of all of these people.

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1. Introduction

Our project is an escape room experience titled “Repairbot F.I.S.H. and the Asteroid of Annihilation.” Players solve puzzles and follow a story like a traditional escape room, but with a twist: rather than being physically present, users interact with the room through a robot. F.I.S.H., a repair robot with a variety of tools, is controlled by the player to solve puzzles in the escape room. The player never enters this room, so they must use a web interface to operate the robot and interact with the room remotely.

This concept required collaboration between the Computer Science (CS), Interactive Media and Game Development (IMGD), and Robotics Engineering (RBE) departments. Our game designers were responsible for creating puzzles and stories evocative of a traditional escape room experience. Our robotics team was tasked with building a fully-functional teleoperated robot, as well as the room in which it operates. Finally, our computer scientists were charged with the development of a website which provided a user interface and facilitated the connections between the robot, the room, and the website itself.

Our goal for this project was to explore what it would be like to create a game where so many different disciplines overlap. This presented some challenges which may not have been encountered in projects involving any of these disciplines individually. These challenges had to be dealt with interdisciplinarily, requiring circular iteration between designers, engineers, and programmers. Our paper will be exploring this process of circular iteration in-depth, as well as the methodology behind individual decisions regarding game design, website, and robotics. Finally, we will conclude with a review of what we learned from the experience of working on this project, and share the advice we would like to give to the creators of future robot escape rooms.

2. Background

Before we began working on this project, we wanted to do research on the different aspects we were envisioning for our game, so we could fully understand what we were making, how it had been approached before, and what we could do to make it unique. It was essential for our project that we understood every different component that went into creating an escape room.

In the 2021-2022 academic year, a group of seniors at Worcester Polytechnic Institute created a Major Qualifying Project (MQP) which explored the concept of a robot escape room. Their project investigated the methods needed to create a teleoperated robot, as well as a modular mechanics-driven environment designed for said robot, which would come together to facilitate an engaging puzzle room experience. This idea bridged the worlds of robotics and game design, focusing on the recreational experience of a player operating a robot in a real, physical space.

Part of the goal for this project to be more than a single experiment which would last one year. It was designed to be built upon, a proof of concept which could then serve as a launchpad for future MQPs. Since this project pitch has a greater focus on user-experience than most robotics projects, but also has a greater focus on engineering than most games, the concept to be taken in a variety of creative directions to be determined by those who expand on the idea. As the previous year's MQP explains, "The final implementation provides a foundation for future expansion and development of robot escape rooms, and we are optimistic for this project's future." (Buckingham et al., 2022, p. 70).

2.1 History of Escape Rooms

The history of escape rooms (ERs) is not an especially long one, as what is considered the first true recorded physical iteration was released in 2007 (Fernández-Vara & Fay, 2021; Ascalon, 2021). The creation of the very first escape room type game goes back a bit further though, with the 2004 indie release of *Crimson Room*, by Japanese developer Toshimitsu Takagi (*Crimson Room on CrazyGames*, n.d.). This video game– which was the first of its kind to feature the now notable "escape the room" theme– was a surprise smash success with wide reaching influence. It even inspired players to dub the resulting genre "Takagism"— video games that follow what we now know as an "escape room" format— after *Crimson Room's* creator. However, it wasn't until a few years later that developer Takao Kato, another Japanese game designer, would be able to realize his dream of a fully immersive game experience in the shape of the world's first true escape room: SCRAP. Starting off in 2007 bringing the ER experience to Japanese bars and offices as a portable game experience, Kato's vision soon outgrew the scope of mutable spaces and began establishing permanent places of operation in the next few years. SCRAP now has 16 locations across the globe with over 100 different room experiences (*SCRAP*, n.d.; Alex, 2021). From there, it didn't take long for other developers to catch on or incept a comparable idea themselves, and a few years later designers across the world began implementing games of a similar kind, though often with different inspirations and goals, and by 2014 ERs had permeated the global physical game space, where they remain a popular activity for people of all ages across the world today.

With such a dramatic and swift rise to popularity, it begs the question: what spurred this new widespread proliferation? Part of the reason comes down to their versatility, not only for players but for designers. Most recently, significant research has gone into new potential ways of using escape room experiences to combine entertainment with education. Since the goal of immersion in said environment was a key feature in Takao Kato's original inception of the escape room, it has remained one of the central concepts of ERs, which also makes them an excellent learning environment. Many fields have tested the implementation of ERs for learning purposes in recent years, and findings have been promising for using escape rooms in place of other gamification methods in the classroom. Researchers from Universities of Granada and Huelva found that running a 30 minute nursing themed escape room for second-year nursing students had extremely positive results, with a majority of students agreeing after participation that it not only helped them learn the subject, but that it was also fun and motivated them to study more afterwards (Gómez-Urquiza et al., 2019). These students also reported that running through the ER actually helped them on their exams, lending credence to the idea that ER learning helps in both the long and short term learning retention. Researchers also noted the potential for this format to be used to promote teamwork along with individual understanding (Pan et al., 2017). Across disciplines, a similar study was conducted on students learning to program in a higher education setting (López-Pernas et al., 2021). Creating an escape room environment using a hybrid model of "computer-based and physical puzzles" for their space, researchers from Madrid found that a strong majority of student survey responses said they learned more than and would prefer an escape room to a traditional lab session. Additionally, 95.2% of students also reported that they would like other courses to include similar ER experiences, even if they were not for a grade. With escape room experiences that are able to cover all different kinds of lesson plans– like fostering, demonstrating, assessing, introducing and integrating specific content knowledge and skills (Veldkamp et al., 2020)– it's very possible that ERs will become an important part of everyday classroom environments in the near future.

The classroom isn't the only place which is seeing an uptick in practical escape room usage, as both museums and tourist destinations have also discovered the many uses of ERs and have dipped their toes into its undiscovered waters. *Journey to the Beginnings* was a collaborative project that ran for two years across four museums, which aimed to represent and recreate prehistoric times with a more interactive spin (Sofaer & Vicze, 2020). This group combined a team of archeologists and creatives to generate an experience that would take the important educational elements of the museums with whom they partnered and deliver it using an escape room, thus introducing a fun activity to enable learning. Similarly, while *Journey to the Beginning* intended to increase enjoyment in a place of knowledge, a study published in the 2019 International Serious Games Symposium (ISGS) proposed that ERs have been, and continue to be used to lure tourists seeking an experience and impart them with knowledge through their participation in the escape room experience (Bakhsheshi, 2019), thus introducing learning onto a fun activity. Interestingly, while these two methods may differ in their approach, they highlight the use of escape rooms as a gamification lure on their own, as the promise interactive puzzle solving can increase engagement regardless of initial player intent.

This does not mean that player intent is irrelevant. In fact, it is player intent and demand that allows the escape room market to continue to thrive as it does today. "One theory behind escape room popularity… is the rise in demand for 'experiential entertainment'" (Ascalon, 2021), as the world has become increasingly digital and people are more likely to seek out experiences where they can do rather than just see. This sentiment is echoed by Andrzej Stasiak, who, in a study on escape rooms as a new leisure activity in Poland, concluded that their rise in ER popularity could be most commonly one of: "transferring the love of computer games into reality", serving as a diversion from everyday life, satisfying the desire for new experiences, or for the purpose of “making international corporations interested in organizing unconventional integration and motivation events” (Stasiak, 2016). It is this general desire to experience that gives escape rooms their continued popularity in the modern world and also what makes them so applicable as a learning tool. Since the desire to participate in experiences is so powerful, that desire can be focused as a tool to break up the monotony of classroom education, spice up the existence of leisure education, and impart learning in situations where the player was not expecting education. The applications of escape rooms as a tool are still being explored, but the powerful experiences that they are able to deliver continue to satisfy players and lure them into new learning opportunities, expanding on knowledge and encouraging fun.

In this project, we explore a new potential format of escape rooms, utilizing this emergent format in combination with robotics engineering to create a new experience entirely. This project harkens back to the original Takagism genre games which come in a digital format, while bringing the physical elements of what we know as the traditional escape room into that experience by allowing the user to control a remote robot. This new format has enormous potential moving forward, as it opens up the possibility for players who couldn’t normally enter a physical room to still glean the benefits of this game genre, as well as opening up the possibility to combine further technology with the escape room experience. Utilizing the remote control factor of this style, escape rooms could also be used to train users and employees on how to manage machines and technology at their disposal. Further, this technology could also be used to allow escape room businesses to bring their cultural experiences to other places in the world to tease tourism where they are located. While our focus was not on creating these experiences, this combination of technologies opens up new possibilities within the escape room genre, which should be considered moving forward exploring this project going forward.

2.2 Principles of Escape Room Design

When designing our escape room, we considered the basic puzzle solving outline for our room, the types of puzzles we wished to incorporate, our target demographic and the desired impact on our players. The research detailed below helped to guide our design process and decisions.

2.2.1 The Basic Building Blocks of an Escape Room

The basic outline of an escape room is broken up into linearity and types of puzzle. Generally speaking, an escape room's puzzle playing path can either be linear, non-linear, or some combination therein (Wiemker et al., 2015; EscapeHour, 2018). In a linear escape room players are guided through puzzles in a linear order, where all the puzzles must be solved in sequence to get to the end. They are well organized and are noted as being better suited for newer players or small teams. In a non-linear setup many, if not all, of the puzzles are disconnected from each other, meaning that they can be solved in any order. There is no correct sequence in which the puzzles must be solved, and they tend to rely more heavily on hints from the game master for players to continue their progression. This room style tends to suit larger groups best as there are little to no bottleneck moments where all of the players are stuck solving one puzzle. The last puzzle is still usually designed in such a way that it is always going to be the last puzzle a team solves. In a multi-linear or a mixed linear/nonlinear setup there are a series of linear puzzles that can be done in parallel to each other. The paths may all start at the beginning, or they may open up to players as the players progress through the room. There are usually bottleneck puzzles that once solved lead to diverging paths of other puzzles to solve. Multilinear or mixed linear/nonlinear puzzles are usually well organized and have clear sequences. They are suitable for any group size and keep the whole team busy.

Puzzles, while not having unanimously defined categories, can be broken up broadly into physical puzzles, mental puzzles, puzzles that are some combination thereof, and meta puzzles (Wiemker et al., 2015). Physical puzzles, also sometimes known as task or twitch puzzles, are puzzles where players have to physically manipulate objects or the room. These can be puzzles like scavenger hunting for the clues, a maze, or crawling through a laser grid. Physical puzzles are most frequently employed to take up time and are useful for engaging players who are not as into mental puzzles . Mental puzzles are primarily focused on having the players use thinking and logic to solve them. These can be puzzles where a player may have to memorize a list, decipher clues, or pull hints from around the room or previous puzzles to solve. Meta puzzles are not wholly their own type of puzzle, but are special in that they necessitate the use of answers from prior puzzles in order to be solved. They are frequently used as the final puzzle in a game.

Puzzles generally operate in a loop of: challenge, solve, reward (Wiemker et al., 2015). For example, the players could be presented with a lock box (a challenge), they then solve the lockbox, and are presented with its contents (a reward). While “good” puzzles are subjective, it is important when designing to keep in mind whether the puzzle: is integrated into the storeline, is solvable, has all the necessary components to be solvable located within the room (ie, escape rooms should not necessitate that players bring their own screwdriver), and whether the puzzle adds atmosphere to the room.

2.2.2 Existing Escape Room Design Frameworks

There are a variety of frameworks that have been used when designing escape rooms. In a study that centered on creating educational escape rooms, researchers concluded that the room should be designed based on measurable objectives and be learner focused (Eukel & Morrell, 2021). Their general process was to design, pilot, evaluate, redesign, re-evaluate, and repeat. When designing a room the authors suggest making the room highly completable within the time limit to increase learner outcomes, setting the stage with clear rules, instructions, expected outcomes, and game tasks, using groups sizes of 4 to 5 people to increase active participation, and creating an easier first puzzle to set the stage for success. The paper then suggests piloting the room with other faculty and people who have already passed the course in order to discover human error and trouble spots. Then the room should be redesigned based on pilot feedback. Educators should reevaluate after every iteration of running the game in order to make appropriate edits to ensure the most is gained out of the learning exercise. See Section 5.2 for more detail on how this was used for our project.

Another design process is the experience pyramid model. The experience pyramid model is focused on creating a meaningful, memorable, positive experience for players (Heikkinen & Shumeyko, 2016). It has six main base building bricks that should be present throughout a player's experience: individuality, authenticity, story, multisensory perception, contrast, and interaction. These are then grouped into 3 larger groups: core of product (individuality, authenticity and story), target group (contrast), and experiencing (multisensory perception, interaction). The pyramid then breaks those tenants of experience into levels of experience, taking into account experience pre-room and post room. From lowest level to highest they are: motivational level, physical level, intellectual level, emotional level, and mental level (Figure 1). A study conducted by Outi Heikkinen and Julia Shumeyko found that this method of designing has potential to be beneficial to room design professionals but suggested further testing to validate their findings (Heikkinen & Shumeyko, 2016).

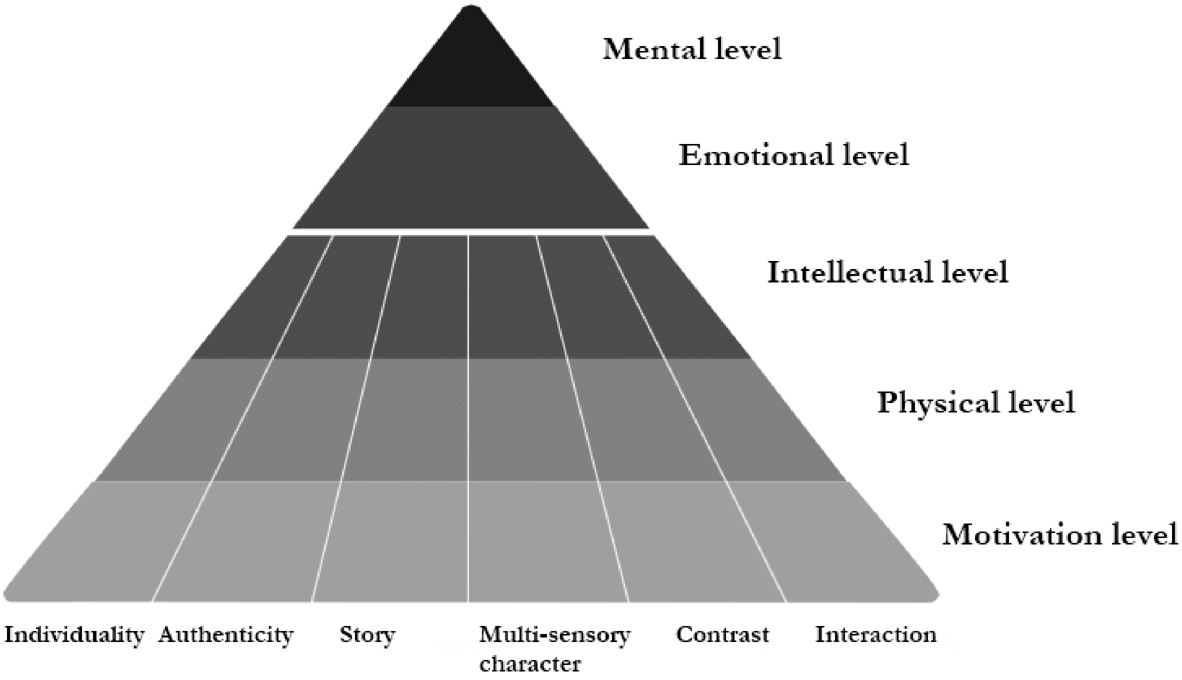


Figure 1: Model of the experience triangle (from Tarssanen & Kylänen, 2005)

2.3 AI in Games

A key aspect in game design is the interactions between the human playing the game and the protocols and systems running the game. Interactions the user has in escape rooms allow the user to develop a perceived relationship with the robot. There are already many ways in which the code can interact with humans in escape rooms to create a more immersive experience, elevate the gameplay, and enhance the storyline.

Artificial intelligence is a broad category, and there are different levels to AI. For the purpose of this paper, we will be using the following definition: "Non-player characters (NPCs) (AI) do not use machine learning techniques but instead rely on simpler algorithmic instructions that give players the illusion of intelligence. NPCs are created to look intelligent and behave intelligently to improve the player's experience with the game" (Coanda & Aupers, 2021). There are many AI models and NPCs that are more complicated than ours that we were not able to implement into our game. An example of a more advanced AI model includes machine learning algorithms and can develop and advance unsupervised.

There are many ways for the user and the robot AI to interact together. One way humans can interact with AI in an escape room is by requesting hints if they get stuck on a puzzle or don’t know where to go next. This is only applicable if the robot or room has been designed to provide hints from someone or something other than a human facilitator. Another way to add human AI interaction is by adding a hands-on tutorial at the beginning of the room, where the AI will walk the human through basic functions of the robot and the puzzles, as demonstrated by last year’s MQP group (Buckingham et al., 2022, p. 34). It is a great way to allow the user to get comfortable with the robot’s controls. Having a tutorial makes it less likely that the player runs into issues with the controls during the actual escape room (Buckingham et al., 2022, p. 34).

AI is an ever-growing field of study, and therefore, the possibilities of how to incorporate it into escape rooms and human interaction will continue to grow as we learn more about it. AI has already enhanced escape rooms, allowing for a more personalized experience for players.

2.5 HRI in the Real World

Human robot interaction (HRI) is the study of interactions and communications between humans and robots; it is dedicated to understanding, designing, and evaluating robotic systems for humans to use. There are two ways a robot can communicate with humans: remote interaction and proximate interactions. Remote interaction is the communication between humans and the robot where the humans and the robot are in different physical spaces; whereas, proximate interaction is the communication between humans and the robot where the humans and the robot are in the same space (*Human-Robot Interaction*, n.d.).

Remote interaction robots are generally teleoperated or supervised, and mobility, physical manipulation, and social interaction can be applied to make the interaction more exciting. When coming to social interactions, it is less important in remote interaction than proximate, since teleoperated or supervised robots are typically controlled to perform actions that are set, and less cognitive aspects are needed for the robots. Remote interaction is more important for proximate robots because they are typically used as service robots. It is essential to have communications between robots and humans to have maximum satisfaction (*Human-Robot Interaction*, n.d.).

In order to perform a series of interactions with the robot, it is essential for humans to build trust in the robot and be willing to accept the potential risks associated with interacting with the entity (Pinney et al., 2022). The robots should be serving after humans, and this should be kept in mind as real robots are created in the real world. For robots that are created to serve humans gives a purpose for the users to trust and utilize them in daily life. As the users spend more and more time with robots, they would eventually become more trusting.

Other than how the robots are programmed, the design of a robot can also lead to a potentially more "seem to be" trustworthy robot. A research on the impact of robotic aesthetics, conducted by Pinney, Carroll, and Newbury (Pinney et al., 2022), has shown that users are willing to trust certain facial aesthetics more than others: cartoon faces are usually more trusted than human faces. But because this is largely related to the preferences of the user, there are many uncertainties around how the appearance of robots should be designed. Adding features to improve likeliness, emotions, feelings, and more social interactions could help to build the trust between the users and the robots (Pinney et al., 2022).

It is also important to have a robot specialized in a specific field so that the robot is more trustworthy to users (Sheridan, 2016). This means that the main functionality of a robot should be focused on its intended purpose. For example, a mopping robot should be able to mop the floor for its users on its own. If it doesn't perform the task correctly, it is hard for the user to build trust in the robot (Sheridan, 2016).

Trust allows a specialized robot to be used properly and perform at its maximum potential (Sheridan, 2016). To create a better game experiment, user-centered human-robot interaction should be used over robot-centered human-robot interaction. A user-centered HRI focuses on how users observe and respond to robots, whereas robot-centered HRI how robots cognize and accommodate humans (Singh et al., 2021). It is also important to recognize the role and relationship between the user and the robot. The human-robot relationship defines how the user should be controlling the robot and also builds more trust between the user and the robot (Singh et al., 2021).

For a tele-operated robot (remote interaction), deep learning is not necessarily needed to be implemented into the program. This means that no machine learning will be performed on the robot, and the robot will be programmed and act as it is. The core interaction between the robot and the player is the communication through remote control. It is crucial to understand how human-robot interaction is related to human-computer interaction so that the interaction can be achieved by communicating through selected sensors. For example, implementing a camera will allow the player to see the scenery, and the view will be displayed on a webpage that the player can access (Singh et al., 2021).

There are many things to consider for a tele-operated robot, while some terms have been defined. For example, the autonomy of the robot will be low in terms of the robot's cognitive skills. This means that the controls of the robot should be well thought off to make controlling the robot easier and smoother. As the user sends demands to the robot, it should receive an understandable amount of short periods to perform the tasks.

To conclude, human-robot interaction is the interaction between human and robots, where the user demand, design, and performance of the robot should be taken into consideration. The trust between the humans and the robots is also essential to complete the communications and interactions.

2.5 HRI in Entertainment and Games

Human robot interaction (HRI) in entertainment and games is an important area to understand when starting this project. By better understanding how humans view and feel about robots during games and how humans change their interactions when dealing with a robot, we can better design our game to give the user a certain experience. When looking into HRI, it is important to look at it through the lens of entertainment and gaming to be most applicable to our project.

A study of Dutch and Pakistani children in two different age groups found that children enjoyed playing with a robot more than they did playing alone, but this did not compare to playing with a second person (Shahid et al., 2014, p. 96). This is important to know that a robot in a game may not be as engaging to a player as a standard multi-person game experience may be, potentially influencing how we decide to model our game design. The study also examined how culture affects human reactions when playing with the robot. The study found that children from collectivist societies, like Pakistan, had more expressive reactions and interacted more closely with the robot than children from individualistic societies, like the Netherlands (Shahid et al., 2014, p. 95). This is useful to know when doing play testing and having a better understanding of why some people may have different reactions to the same situation, is useful when analyzing data collected from playtesting.

When observing how players interact with robots, an aspect to consider is if the robot is able to influence or change the players' behavior. By understanding how the robot can influence players, this could change how certain aspects of the game are experienced based on the players behavior. Adding in player assistance in games is a great way to keep players motivated on more difficult puzzles and decrease player frustration during the game. It was found in a 1997 study that when a robot gives a player assistance during a task or puzzle, the player is much more likely to work on the puzzle for longer (Fogg & Nass, n.d., p. 332). It was found in a 2021 study that players are more likely to see a robot as fair when the robot starts the interactions as compared to if the player has to start interacting with the robot (Sandoval et al., 2021, p. 860). This is important to know when introducing the robot to the player and figuring out ways for the player to gain trust in the robot.

Trust is important in any game, but it is especially important when one of the players is not human. This can make it difficult to build trust and cooperation between the human player and the robot. A study in 2019 found that trust in the robot in a simulated escape room increased when the robot communicated to the player using an algorithm that would ask a series of questions based on answers to previous questions (Gao et al., 2019, p. 309). By having a more flexible communication style between the robot and the player, trust will increase and the player will be more likely to accept hints or suggestions from the robot.

There is also a question regarding if part of the experience may be lost without another human. This belief is refuted by a study from 2000 that claims that humans will react mindlessly and without thinking when working with a non-human robot with more positive experiences than with a human robot (Nass & Moon, 2000, p. 92). By reviewing HRI studies specifically in regard to games and trust we were able to better understand how humans may react to our project and the underlying reasoning for those reactions.

2.6 Accessibility in Games

Traditional video game and paper game experiences have not historically been accessible to people with disabilities of various types. In recent decades we have seen an increase in accessible video games through the use of screen readers, braille displays, added labels, and custom created controllers. The information and research detailed below helped to inform our design goals and decisions. For more information on how this research manifested in our project please see Section 3.2.

A common type of mechanism used for adapting games, specifically for the blind and visually impaired, is utilization of additional audio or tactile feedback (Grammenos et al., 2006, p. 282). This is achieved for video games with screen readers, a software that verbally describes to the user what is on the computer or phone screen. The software also tracks where the cursor is and describes what the person is about to press. This is a way for blind and visually impaired people to surf the web and play simple video games. However it becomes more difficult to use when the video game or webpage is not optimized for use with a screen reader, making understanding how to play the game or accurately explain the image difficult or impossible for the player.

Another mechanism used to make video games more accessible to the blind and visually impaired is a braille display, which is connected to a phone or computer (*An Overview of Braille*

Devices, n.d.). This is a tactile form of input that allows the user to read the screen using a machine with cells that raise or lower to reflect the correct braille for the reader. These devices have a way for the user to input braille into the computer and also have basic navigation functions. This is very useful for people who are not familiar with the standard QWERTY keyboard or may also have hearing loss with their vision impairment. For physical board and card games it is easier to create or modify games to be accessible to both the blind and non-blind community. Creating large print versions with braille labels on cards and pieces are an easy way to allow for collaboration between differently abled people.

For those with physical impairments it can be helpful for games to allow different controllers to be used. A great example of this is the XBox Adaptive Controller, which is a customizable option for people with various physical impairments to optimize the available controllers so they can more easily play video games that may be otherwise inaccessible ("Xbox Adaptive Controller," 2018). This has inspired many companies to create similar adaptive controllers that can be mapped to a custom mouse setup for easy and more widespread use. For physical spaces there are aids for playing traditional lawn games like shuffleboard or indoor table tennis tables that can accommodate wheelchair users. More accessible playgrounds with smooth terrain and ramps have been becoming more popular as a way for many differently abled children to play together. However, it is very difficult to find adult physical spaces with the same amount of accessibility; a great example of this is escape rooms, these are often smaller spaces with puzzles that can rely on fine-motor skills, physical strength, or balance. This is not accessible to the physically impaired and excludes them from these spaces.

The design of games to be accessible from the start is an interesting way to create more accessible games. A great example of this is the game Access Invaders, a universally accessible version of the classic game Space Invaders. This game took into account a wider range of players than the traditional video game design calls for, including people with physical impairments, vision impairments and developmental impairments (Grammenos et al., 2006, p. 391). By designing with these populations in mind they were able to create a video game that was fully customizable to each person's abilities and has built in accessible features where possible, such as a fully audio option and a built in screen reader and compatibility with 3rd party adaptive controllers. A unique feature of this video game is that multiple people with various abilities can play at the same time on the same computer. This is usually not possible due to the logistics of retrofitting most games to be played by people with disabilities to be single player or only support one player per system. Accessibility in games has become a larger market and more game designers are realizing that this is a great option to include more inclusivity into gaming. For more information on how this research influenced our design please refer to Section 3.2.

2.7 Background Conclusion

The research we have done for this section helped guide us during our project. The ideas and processes helped us in our design of our escape room and gave us pointers on potential areas we wanted to explore. We were able to integrate our research into the work we produced to create a stronger and more informed final experience.

3. Designing the Game: Repairbot F.I.S.H. and the Asteroids of Annihilation

This section of the paper presents the development of the final playable escape room: Repairbot F.I.S.H. and the Asteroids of Annihilation. This was the culmination of last year's project and this year's research. The section is divided into two parts. The first part describes the various components of the escape room, including the storyline, puzzle design, and the integration of the room, robot, and website. The second part outlines the team's efforts to incorporate accessibility into the project, with the aim of making the escape room more inclusive for a diverse range of people than traditional escape rooms.

3.1 Final experience

The final product is a one-room escape room experience with a robotic companion to help the player escape the room. This includes a narrative storyline presented to the player through the website and theming on the website to tie into the worldbuilding created over the past year. The experience consists of multiple puzzles that require remote control of the robot by the player in order to complete, including a Simon Says type puzzle, a hidden message, and a door code scan that must be completed using the robot and its tools. The game also includes puzzles that rely solely on the player's knowledge, like a word jumble.

The storyline follows a spaceship that is being used to deliver some questionably legal goods to a high security space station, when their ship unexpectedly enters an asteroid field which takes out the communications tower on the ship. The player must now control the robot to escape the area where the robot is currently trapped and fix the ship to make it through the asteroid field safely (Figure 2).

MQP - Robot Escape Room

Walrus: Hey guys, I'm picking up a lot more interference coming up here than the ship predicted…

Shrimp: Are you sure? Rerun the numbers

Walrus: Yeah I'm telling you these calculations don't match what I'm seeing

Shrimp: Hang on I'm coming down

Books: Have y'all figured out those numbers? A bunch of high speed debris just popped up on the radar and we're heading right toward it-

Frenzy: WE'VE BEEN HIT, MOVE TO YOUR ST-

Walrus & Shrimp: where did they-...- out of nowhere-... -need to access-...-send out- -should still work-

Books: WE'VE ENTERED A FIELD, ENGAGING EVASIVE ACTION

Bravo: we're taking heavy damage, shields are failing on all sides and we lost the auxiliary processor on the top deck

Books: I can't get a status from Walrus and Shrimp does anyone have contact??

Bravo: Power is out in decks one…and 12, patching over to-

Red Rover: I can't get communications under the first floo-...-gnal tower's hit, dispatching repair robo-

Books: … -hit! Rover?? Are you there? Can anyone hear? Op Con, you're close I need you to.. -onnect into the dispatched bot and fix the signal tower before we-...-or we can't dock to get out of this… -ield-

Figure 2: Narrative shown to players in beginning of game

The puzzles the player encounters are to be completed in a mostly linear order as a way to simplify the logic and creation of the physical escape room, with some wiggle room to allow players to explore their surroundings. While the puzzles must be finished linearly, they may be started in a parallel order (see Figure 3).

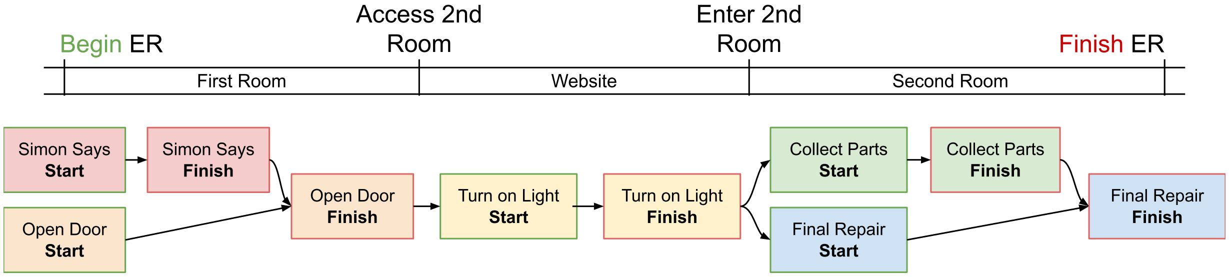


Figure 3: Timeline of Puzzles

First, the player must play a Simon Says game which involves having the player navigate the robot to each corner of the room following blinking lights in order to calibrate the robot, this puzzle also has the added benefit of teaching the player how to navigate using the robot. Following the Simon Says puzzle, the player is able to begin the second puzzle: Opening the Door. The first part of this is discovering a hidden word jumble puzzle on the wall using a blacklight on the robot. This helps the player begin to explore the additional tools available on the robot. After unscrambling the word correctly, the player must enable the robot to scan a code on the wall asking for a password, and input the code on the website, at which point the door will begin to open, before the website prompts the player with a wire rotation puzzle originally part of puzzle Turn on the Light with the narrative explanation that the wiring of the door is messed up and needs to be manually repaired. Once this puzzle is solved, the door opens the rest of the way, and the player wins the room. Puzzles Turn on the Light, Collect Parts, and Final Repair (as referenced in Figure 3) were not physically realized in our final room, but all puzzles are discussed in further detail in Section 5.1.1.

The physical room puzzles required the robot to be able to interact with them by using a camera attached to the robot. This allows the player to see where in the room the robot is at a given time and also allows the player to scan codes automatically. The camera is able to tilt up and down and also has a set of blacklights and regular lights to help solve the puzzles. The room, as shown in Figure 4, contains multiple sensors and mechanisms to allow the robot to complete the puzzles while giving the player a fulfilling experience while completing them.

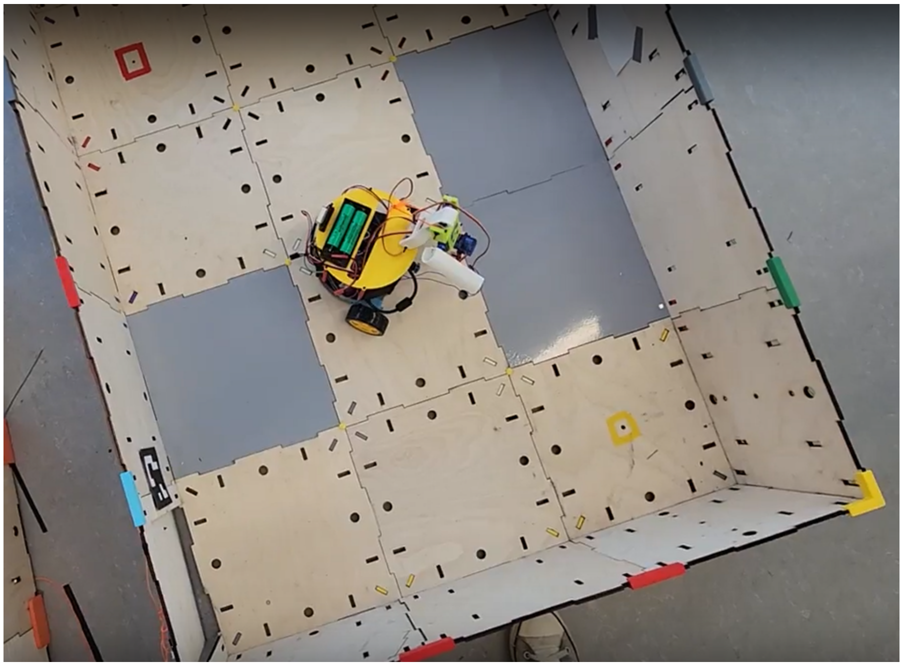
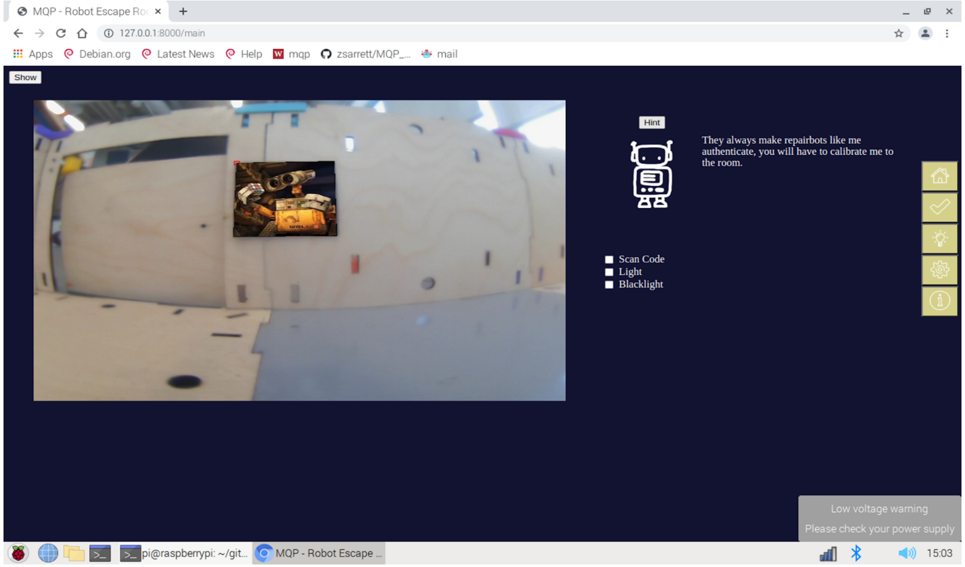


Figure 4: Robot inside escape room

The website combines all the aspects of the experience (the robot, room, and player), creating a cohesive experience for the player. The website, as shown in Figure 5, delivers all story elements to the player to allow for a more immersive experience. The player also inputs solutions to puzzles that do not rely on robot manipulation to solve in order to give a variety of puzzles to the player.



They always make repairbots like me authenticate, you will have to calibrate me to the room.

Low voltage warning

Please check your power supply

Figure 5: Screenshot of website

This project was a unique combination of Interactive Media and Game Development (IMGD), Robotics Engineering (RBE), and Computer Science (CS) theories and designs that needed to work together to create a cohesive and entertaining experience for players. The diverse skill sets of our team members contributed to the development and iteration of this project and concept of a robotic escape room.

3.2 Accessibility in Our Project

We consciously developed accessible elements to the escape room as it was developed. The target audiences for the escape room then expanded to hopefully successfully include people with developmental disabilities, physical disabilities, and hearing loss. These populations were thought of in every aspect of the game and puzzle mechanics as well as the room and robot itself.

For the website accessibility we included both visual text for the introduction narrative as well as audio of the same text. This allows both people with hearing loss and people with autism and ADHD to be able to understand and play the game more easily (Fotaris and Blake, *ECEL*

2022 21st European Conference on E-Learning.pg 43). We also added the hint page to allow players to see the hints they have already been given, helping those who may forget them quickly. The player can also change the audio level to their preference.

For the puzzles we originally had a color sequence that players would have to follow to solve the Simon Says puzzle, however we wanted to make it accessible to people with different types of colorblindness, so the puzzle was adjusted to have all lights off to start and flash the corners the player needs to head toward in sequence. This eliminates the need to distinguish the colors of the lights and only need to see the difference in brightness from the flashing and non-flashing lights.

For the robot control it is currently set up to be controlled with only a bluetooth keyboard. However, it is simple to switch the controller to a more adaptive one if a player needs it with very little change of the game needed beforehand.

The game is also completely played while staying in one spot and does not require much movement. This is useful for people with mobility issues to allow them to still play and experience an escape room.

4. Co-Constrained Circular Iteration

While our natural inclination early in the project was to approach things linearly, we quickly began to run into roadblock after roadblock as each new path we pursued led to constraints that could only be fixed by switching focus. This forced us to reevaluate after only a few weeks and switch to an iterative style conducive to creative interdisciplinary work: circular iteration. This way, the project is able to accommodate multiple diverse mindsets and areas of focus to iterate together, blending ideas and informing each other of conflicts which would prevent certain concepts from being implemented.

4.1 What is Circular Iteration?

Throughout the entirety of making this project, our team needed to be aware of the cyclically constrained development process necessary to interdisciplinary creation. Due to the nature of this project, we had three separate major disciplines working together– Computer Science, Interactive Media and Game Development, and Robotics Engineering– to create a cohesive final design, which also meant that we had three separate sets of constraints that needed to be considered. This determined that there would be points in the process where one team needed something from another team, who in turn could only make so much progress before they too met a stopping point caused by needing something from another team: such as how the puzzles inform the robot functionality, and the robot capabilities dictate the ways that the puzzles can be set up. To accommodate for the lack of linearity in the project, our group chose to approach this using a method we call circular iteration (see Figure 6).

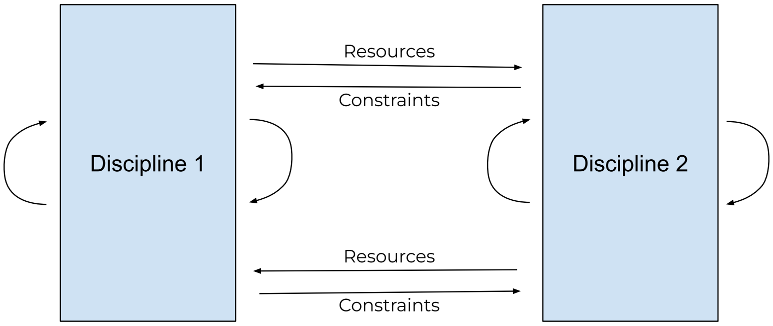


Figure 6: Diagram of design process, inspired by AI Based Game Development Process (Eladhari et. al, 2011)

In the case of this project, which contains multiple teams with resources and constraints, circular iteration is defined for our purposes as each team continuing to work towards their goals until their constraints outweigh their resources, at which point said team will pause until the limiting constraints are dealt with by the teams under whose domain they fall. Examining in more detail, a constraint is a factor limiting progress caused by something outside of the control of the team with the constraint. Examples of constraints that occurred included IMGD working around the smallest size a robot can be, RBE considering the allowances for puzzle positioning, or CS keeping in mind the robot's field of vision. A resource is the opposite: something on which progress can be made without any interference from another team, and often one team's resource is another team's constraint. Some examples of resources are IMGD choosing the puzzle input types, RBE designing the arm motion, or CS setting up the website layout. Each of these factors work together, and need to be solved together, making circular iteration is the best method by which to do so.

It was also unlikely that any one team member would know the exact details of every part of the project, especially in a project where every part is likely to be out of scope of at least one member. This meant that every team member was likely to encounter something outside of their area of expertise at least once during the course of the design process, at which point they would need to collaborate with other team members who better knew what they were working with. By this method, every part of the project would be passed around, and adjustments are made until either a limiting factor is reached or until the element is completed, allowing for much more complex iteration to happen interdisciplinarily rather than having each aspect of each discipline stand alone.

Circular iteration was an extremely important element to this project, as it allowed our many disciplines to communicate and work together to push each other forward, instead of holding each other back. Not only did IMGD, RBE, and CS all need to work in tandem, but each major discipline contained subteams which also needed to iterate circularly on their own. This meant dealing with the various constraints pulling in non-congruent directions from each major discipline team, as well as the subteams contained by them. Within IMGD, for example, there quickly became a distinction between the narrative requirements and the mechanical inputs, at which point we designated these two subjects as their own subgroups to iterate between.

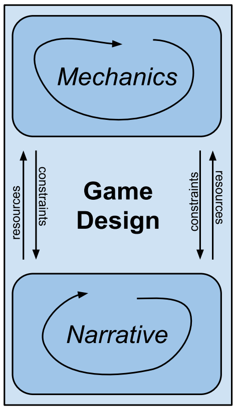


Figure 7: Game design constraints

This distinction was important to create due to the push-and-pull nature of the narrative and mechanical requirements that arose in development (Figure 7). As narrative develops, it pushes the scope for the mechanics into position, and as the mechanics are developed with theme in mind, they need to be pulled into the surrounding story context with more intention. This cycle then needed to be repeated with small adjustments until an interesting puzzle which makes sense within the context of the room that was created.

While developing the narrative was important in developing ambiance and contextualizing the puzzles, our main focus for this project was to explore and develop on the potential for puzzles in this unique format. Therefore, early stages of this iteration had us building mechanical puzzles in detail with a rough narrative theme in mind. We developed our mechanics until they were fleshed out enough to compare with the robot's functionality, at which point we gave very rough narrative tie-ins (e.g. opening the door to get access, harvesting necessary parts, etc), ensuring that each puzzle had narrative reasoning that not only worked with the puzzle itself, but also worked cohesively to tell a story as the player made their way through the experience. For example, we knew at this point that some of our puzzles would be approachable in tandem, so we added a few mechanical constraints backed by narrative to ensure that players would play the room in the order that made sense. For instance, in our first two puzzles, where we knew the player would be able to find the door password before they completed Simon Says, we added the narrative constraint for Simon Says that the player cannot proceed forward with the door puzzle because the robot "needs to be calibrated" by the Simon puzzle to gain access to further parts of the ship. Now IMGD had a draft of mechanics which could be passed to the robotics and computer science teams to be checked for feasibility, as much of our circular iteration between teams came down to "do we think this facet of the game is possible within the constraints of other teams," as further discussed in Section 5.1.

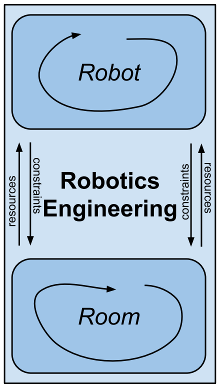


Figure 8: Robot design constraints

Not only was there a push-pull relationship between the robotics team, CS team, and the Game design team, but also within the robotics team. The robotics team was split into two subdivisions: designing the room and designing the robot (Figure 8). The room and robot subgroups had to collaborate closely in order to ensure a realistic and believable experience for the player. The room team had to coordinate with the robot team in terms of size of both the robot and the room so that the room would not be too small and cause issues for the maneuverability of the robot and the robot could not be so large that the room would have to be huge in order to accommodate it. This led to a push-and-pull design relationship that operated alongside the puzzle mechanics requirements. As the robot group figured out the type of manipulators to use for the puzzle pieces, the room team had to figure out how to present the piece to the robot inside the room that would allow for the manipulator to grasp the piece appropriately. As the room team designed a doorway, the robot team then had to use that height to constrain the arm they wanted to include. This cycle of co-constraining of the room and robot continued over the many design iterations the entire group went through, and is discussed further in Section 6.

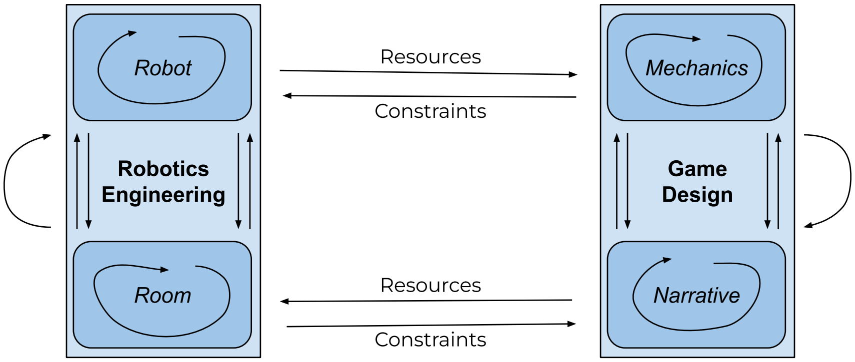


Figure 9: Full project design constraints

Once each cycle of subteam iteration was completed, we needed to regroup as an entire project collective to evaluate where more work needed to be focused, and whether the work that was just completed is compatible with other teams' work. With each new iteration, we needed to locate the accompanying set of constraints and resources for how to iterate next (Figure 9). One case of this happening occurred very early on in our process, where we encountered a point of friction in the development of the puzzle and robot designs: the robot needed to be designed for the puzzles and the puzzles needed to be designed with robot capabilities in mind, which should go first? As this chapter suggests, it was decided for development to start with both and then continue to develop circularly. This meant that both teams began working, with the robot group deciding that they wanted the base to be rounder and shorter and puzzles beginning to generate potential inputs and outputs. These designs were then compared against each other, each earning feedback and returning to the drawing table to incorporate. The first iteration of puzzles, for example, did not consider the robot as a delicate instrument acting within our room, and ultimately needed to be rewritten to avoid causing impossible obstructions for the robot. Similarly, last year's iteration of the robot had the option to turn the camera separately from the robot body, which left players confused about their orientation in the room during playtests and ultimately required us to reconsider how the player would be allowed to look around the space.

After several of these rounds of iteration, we came to a point of convergence where everything we had iterated on up until this moment needed to be tied together under our website interface. Since the website (which until this point had remained a series of disjointed pages) was meant to serve as the home base of interaction for this project, this moment of combination was very important. This meant adding another layer to our existing circularly iterative process, and making sure that this layer was as cohesive with the others as it could be (Figure 10). Much of this effort to foster cohesion came from connecting the website to both the room and the robot, which both dealt with the puzzles. Since the room runs the puzzles, and the robot interacts with the puzzles, by having the website control both it allows the website to sandwich the subteams of both the robot and puzzle teams into a single iterative factor, at which point we were able to add in website functionality while still maintaining the sanctity of our circular iteration process.

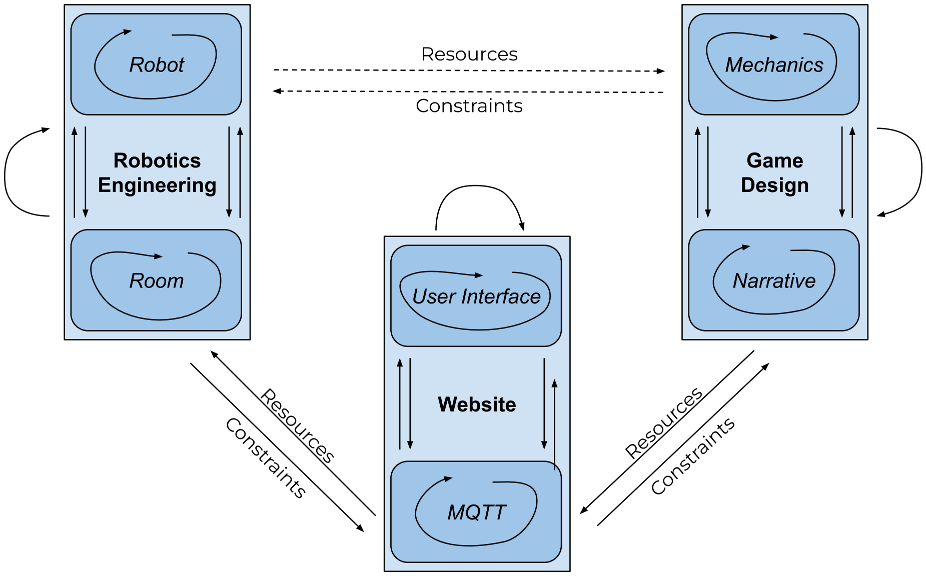


Figure 10: Design constraints with website

5. Game Design Methodology

In this section, we will discuss the design process for the puzzles, narrative, and website interface for our project. We will begin by discussing the experience goals that guided us through the entire project, followed by a more detailed look at the design process itself and how we arrived at our final experience design. Next, we'll discuss some of the puzzles which didn't make it through to the end and why exactly they weren't a good match for our project. This leads into a discussion of designing for the resources at hand, first talking about designing with the constraints of a robot, then talking about working on the inclusion of modularity as a given tool. Finally, we discuss the multiple phases of playtesting and iteration through them, as well as the techniques utilized during playtesting.

5.1 Game Design

In this section, we will specifically go over our game design goals, accomplishments, and process explanations. We will discuss our iteration process and why certain content was included or cut from our final design.

5.1.1 Final Designed Puzzle Experience and Iteration

The complete designed experience of our game had players move through five separate puzzles meant to be done one after the other, though some can be approached non-linearly. While these five puzzles were all completely designed, the physical experience we were able to complete includes only the first two and a half, as discussed in Section 3.1. These puzzles will henceforth be referred to by the following names, with the understanding that they are meant to be played in the order that they are listed (Figure 11):

1. Simon Says
2. Open Door
3. Turn on Lights
4. Collect Parts
5. Final Repair

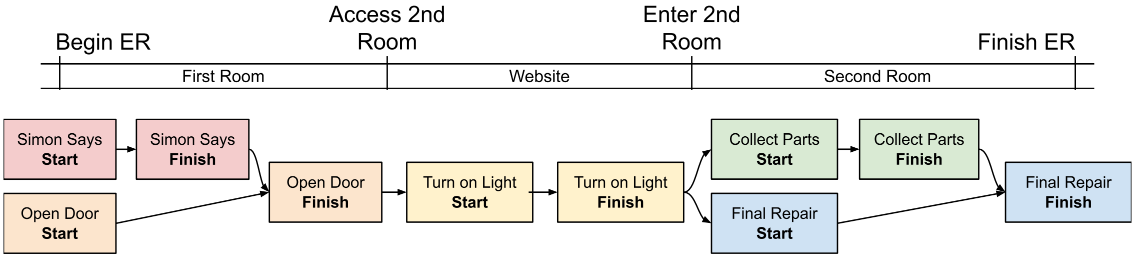


Figure 11: Puzzle Timeline

The first of these puzzles is Simon Says, whose name comes from the classic game which inspired the mechanics: classic Simon Says puzzles involve having players remember a pattern of lights that are flashed and then repeat the pattern, which grows by one additional light flash with each new round until the player fails to repeat the pattern correctly or quickly enough. We knew we wanted our first puzzle to involve the player input of moving the robot around the room at this point, as we felt it would serve as a good first tutorial point. Taking inspiration from games like Portal, we planned to slowly roll out mechanics over time so that players would be able to learn each new skill as it was introduced without overwhelming them. The first of these skills that we wanted them to learn was how to control the robot’s movement, so the idea of pulling players from point to point with a Simon Says type light mechanic was one we gravitated towards. However, we quickly found that driving back and forth the amount required for true Simon Says was more frustrating than anything, and required more skill than the players would need in order to get comfortable with the controls. From there, we simplified the puzzle to moving over pressure points in the correct order as indicated by a sign on the side of the room with the narrative reasoning that the robot needed to be “calibrated to the room”, which we playtested at Alphafest. From there we further simplified based on playtesting data (see Appendix B) to having pressure points indicated by blinking lights that turn solid when the pressure point is driven over and set the next set of lights to blinking on. Once all of the sets of lights are solid on, players can complete the next puzzle.

Our next puzzle could be completed partially in tandem with Simon Says, which we referred to as Open Door. This puzzle was about opening a door to the signal tower bay (as indicated by the on-the-nose name), but has entirely unrelated mechanics to do so. Players start by scanning a code near the door which prompts them to enter a password. At another location elsewhere in the room, the player could then shine the blacklight to reveal a word unscramble with two sets of letters: one in red, one in blue. The colors red and blue were chosen as they are the least likely to be affected by colorblindness, and the way the different inks interacted with the blacklight allowed them to be distinguishably different brightnesses. The red letters unscramble to form the word “PASSWORD”, while the blue letters unscramble to the actual password to be entered: “ROCKET”. There are also a different number of letters from the actual password and the word “password”; the password entry tells the players that they needed to enter six letters to make it clear that “password” was not the answer. Once unscrambled, this word can be entered to open the door, but ONLY IF the player has already completed Simon Says to “calibrate the robot.” If they haven’t, they’ll be met with a popup requiring them to calibrate to the room before they are allowed to continue. Having this series of mechanics allowed us to give players a mental challenge that was bolstered by the robot’s mechanics, as well as allowing us to create an interesting physical feature in the room: an opening door.

Our third main puzzle begins as the robot moves into the secondary space of our escape room. The robot is characterized as stubborn and uncooperative, refusing to work and complaining about OSHA regulations due to the lack of light in the new area. This prevents the player from using the robot arm until they turn the lights on, which requires them to solve a series of puzzles on the webpage. First they have to select the correct three symbols from a list of six displayed on the main webpage to open up remote access to the electrical panel for this segment of the ship. The webpage gives no indication of which symbols are correct, so they must be located on the walls of the second room using the robot's flashlight. Then players have to complete a puzzle where they rotate tiles on a 4 by 4 grid (Figure 12). Each tile has small segments of split wires, and the puzzle is complete when they all connect in a complete circuit. This restores power to the second room of the ship, which turns on the lights, putting the robot in the mood to re-enable the robot arm, and allow the player to proceed to the various objectives within puzzle 4.

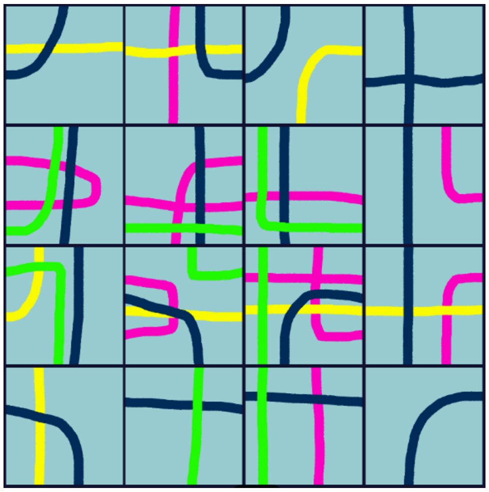


Figure 12: Tile rotate puzzle

Our fourth puzzle marks the start of the player's time exploring the second room with all of the robot's tools at their disposal. This is the first time they will need to use the arm and magnet as well, as puzzle four is meant to highlight the robot's ability to use its extremity. This puzzle's narrative explanation is the first step towards actually repairing the ship: gathering the parts to fix the signal tower. There are three parts positioned strategically throughout the room which need to be harvested so that they can be placed in the final signal tower assembly to "repair the damage done to it", and subsequently winning the escape room. However, placing the parts is puzzle five, puzzle four is just about gathering them. Our initial plan for this puzzle was to create a "WOW" moment, as had been recommended by the founders of Escape New Haven, Max Sutter and Ethan Rodriguez-Torrent during our interview with them. They described a WOW moment as being something that makes the players say "woah that was cool, how did the designers do that." Our solution to this was to have a moment in our escape room where things seem to be looking up before disaster strikes again. Our narrative reasoning was to tell the player to grab some parts from a box, at which point an asteroid would hit the ship, knocking these parts into obscure locations to be gathered for puzzle four. This goal quickly grew out of scope though, as we realized how unpredictable the falling parts would be. Instead, we opted for a simpler story: gather replacement parts by harvesting them temporarily from other parts of this ship panel. This meant that the parts could be predictably pre-placed. We then created three different locations for the parts and their mechanical puzzle structure:

1. Inside of a series of tubes along the wall of the second room. This replacement part is a magnetic piece, and can be grabbed by players using the electromagnet at the end of the robot's arm when precisely navigated along the pipe's track.
2. Behind a screwed down wall panel in the second room. Players can use their magnet to pull the screws out to release the wall panel, at which point they can reach inside of a wall cutout using their gripper to gather the replacement part.

3. In back of a stack of prop crates in the second room. These crates have been designed on sliders, and when the player pushes them with the robot arm they move out of the way so that the gripper arm can reach through and grab the replacement part.

All of these parts need to be gathered to be placed inside of the final signal tower to repair it, meaning that while this puzzle can be started in tandem with puzzle five, it must be completed before puzzle five, the final puzzle, can be completed.

Our fifth and final main puzzle utilizes the signal tower in the center of the second room. There is a compartment with a lid that has the text "SUBMIT PASSWORD". Shining the blacklight reveals that several letters have been highlighted, now showing the message "**S**UBMI**T** P**A**SSWO**R**D". This reveals that the password is "STAR", which is also reflected by the room's inclusion of decorative paper stars with designs drawn in blacklight ink. Once the password is entered, the parts compartment will open. With the compartment next to the signal tower open, the player will find three differently shaped holes near the base of the tower meant to represent parts which need replacing. These holes fit all three of the pieces discovered in puzzle 4. If they have all been collected, the player simply needs to place each object in the correct hole to fix the signal tower and complete the escape room.

Within our final product, only the first two of our five puzzles were fully realized. After a good deal of paper-prototype testing and feedback, we were unable to finish the physical realization of our second room due to time constraints, meaning that Collect Parts and Final Repair were not playable in our final product, despite being fully designed. The rotating tiles portion of our Turn on Lights puzzle was made playable before the door can open, with the narrative justification that the door is jammed and the wires need to be reworked in order to get it running properly. This first room only is best played in 15-20 minute increments, and the puzzles in this space playtested well with players after several iterations.

One key feature which makes escape rooms appealing is that they excel in providing both narrative and mechanics. Without narrative, mechanics are a collection of chores with no throughline. Without mechanics, the narrative ceases to be interactive, and the player has no direct involvement in the experience. Thus, a blending of the two concepts is necessary to create an enjoyable experience, which we find in a combined concept: puzzles. Puzzles consist of a series of connected mechanics and associated hints that guide the player through the narrative, bringing together individual elements and giving them meaning through the setting and story. Puzzles make up the main focus of an escape room experience. Thus every component of the escape room must be considered in both narrative and mechanical design contexts to create an enjoyable interactive experience.

5.1.2 Designing our Narrative Experience

The initial narrative theme we identified was “used future”. The used future aesthetic “imagines a future in which some things have evolved well beyond modern imagination, while others remain almost identical to their contemporary form.” (McCoy, 2022). This aesthetic is characterized by having gritty, well-used technology, only held together with chewing gum and duct tape; used future is often credited as being popularized by media like the Star Wars and Alien movie series. Used future was chosen as our thematic starting point for a few reasons:

1. We wanted a theme that would make sense with the materials at our disposal.
2. To further engagement and concentration, we wanted a theme that would be high stakes but without being bleak or overwhelming.

3. It seemed appropriate to choose a theme that would capitalize on the unique combination of robotic, digital and game-related elements in our project.

The first of these reasons comes down to the fact that we knew that we would be working with. Based on the work of last year's MQP, we knew that the materials of the room would likely be constrained to laser-cut wood panels, 3D printed parts and props, and laminated stickers. This meant that creating a convincing high level science fiction aesthetic would be difficult, and it would also be difficult to create a very natural outdoorsy scene or a well put together mansion, museum, or mall. However, the used future aesthetic is built on the idea of high functioning technology held together by scraps and parts (McCoy, 2022); having a room for players to explore built only with the materials proposed by last year's MQP would already fit within the used future aesthetic. This also meant having a robot would make sense within the setting, especially a robot with higher level artificial intelligence and physical limitations. The used future aesthetic promotes technology that is in some ways more advanced than possible in the modern world, but is in other ways just as or even more limited than today's tech. Having a robot with the ability to converse with emotion and personality is advanced enough to meet the first category, while being low technology enough to lack the ability to move without an operator meets the second. We needed this narrative justification to give our robot personality while still having reason for the player to control its movements, which was meant to further a different design-based motive.

During our research phase we had identified the importance of teamwork inside of an escape room (Pan et al., 2017). This presented us with a challenge, as our experience was designed to be played primarily by solo players. We needed to consider how we would foster "teamwork" in a space with no team. The answer came in the form of our robot. We decided by giving our bot a personality and portraying it as a “teammate” to the player within the narrative, we would be able to create an experience which simulates teamwork within a solo experience.

The second reason for choosing a used future as our initial theme was to create a situation for players that would be high stakes but not hopeless. With the experience goals of engagement and success in mind, we knew we wanted a story where players needed to be fully invested in the story and the outcome. Since used future narratives often involve the characters contending with the hostile nature of space with high stakes as an everyday obstacle to survival (Luttrell, 2020), we knew there would be high stakes under a “used future” theme no matter what story we decided to tell. We also knew that these high stakes everyday occurrences are not survivable without the interference of characters in those stories, meaning that we would be able to come up with a story where the player interactions are integral to the success of the narrative.

This also played into our final reason: we wanted to capitalize on the unique form of this project. While we had initially considered some themes related to other facets of our interdisciplinary project; most notably the ideas of exploring from a mouse's point of view, presenting an educational experience about the human body, or a spy-based stealth mission. However, what each of these ideas lacked was a way to justify having the user control a robot, at least without somehow disguising the robot narratively or otherwise giving justification for why the controls existed as they did. Not only did we worry that this might make the experience feel too close to a video game instead of a physical escape room, but we thought it detracted from the unique combination of elements to disguise our robot as something else within the narrative. The combination of digital and robotic elements allows for potential not possible in a purely digital game, choosing a theme that would make our game feel like a video game felt reductive, and we wanted something to better highlight the uniqueness of the elements our game combines. Used future is filled with quirky machine companions– from *Star Wars'* R2-D2 to *Prometheus'* MU/TH/UR (McCoy, 2022)– so we knew that it would make sense to incorporate our player-operated machine into the narrative storyline as a literal robot, highlighting the physical element of our game structure and the work of our robotics engineers.

The final story we established follows our player using the controls of our robot "F.I.S.H." to help navigate around a ship to fix the damaged signal tower. The twist? The spaceship is being bombarded by the asteroid field it is passing through, and cannot dock to get out of the storm until their signal tower is repaired. In our own story writing, we also brainstormed that the ship, "The Aquarium", was a cargo ship delivering goods of questionable legality to a high security base and filled with a crew that frequently turns over. The world of The Aquarium is one of oligopolies, poor healthcare, and thriving capitalistic ideals. This is why we decided the delivery being made is meant to go to a corporation who wanted to cut corners on an expensive purchase. This backstory allowed us to come up with further environmental storytelling elements, most of which had to be left out for time. More importantly though, it helped us form a better idea of the experience we wanted to deliver as we began putting together the finishing details on our project.

5.1.3 Experience Goals

One of the first questions that needed to be answered when creating this interactive room is, "how do we want our players to feel while they engage with our experience?" The answer then guided the previously discussed decisions as well as many more, since every design question could be approached from the perspective of, "what will this elicit in players?" As such, one of the first goals in designing our escape room was to identify broad feelings we wanted our ER to create in players, which we were able to narrow down to four general concepts: excited, stressed, concentrated, and immersed. Excited players bring that excitement forward with them as a sort of continuous momentum pushing them through the experience. We want to capitalize on this forward movement and engage our players in a way that encourages them to keep up this energy. Having puzzles that are too difficult or too easy can stymie this excited feeling and leave players feeling frustrated instead, so we needed to create puzzles which would engage players with a mystery between them that is engaging enough to maintain that level of excitement.

In order to maintain excitement in our players, we decided we wanted to create a sense of urgency to create a feeling of stress to further motivate our players. This was a tricky balance, as we didn't want our players to feel overwhelmed or anxious, but instead we wanted them to be just stressed enough to be fully enraptured by the experience. In order to do this, we chose a narrative story which would create a naturally stressful environment– a survival based situation– and then built upon it with puzzles which could be completed within the time limit but not easily, making beating the clock the real sense of stress. Then, adding narrative elements that further highlight the severity of the situation continues to build that urgent sense of stress, which in turn boosts the excitement of players, particularly those dopamine seeking players (Pruessner et. al 2004).

That feeling of urgency is vital to generate another important element of the experience we wanted to create: players should feel concentrated on the space and capable of moving forward. To get players to concentrate on each puzzle, they need to be difficult enough to keep players focused and not bored, but not so difficult that they're discouraging; puzzles need to have enough difficulty to feel successful on completion of a puzzle but not so difficult that success doesn't feel worth it or possible. We want players to feel in control, as if their success is just over the horizon and all they have to do is get there. More specifically, the ideal case is to create an environment where players can enter a flow state. Popularized by positive psychologist Mihaly Csikszentmihalyi (Csikszentmihalyi, 1990), a flow state occurs when someone is completely engrossed in a task or activity, which can only happen when the activity is one that the person feels confident in but that creates enough challenge to keep them from feeling bored - similarly to the description of concentration we had aimed to achieve. Thus, flow serves as the ultimate goal for our players concentration, but considering averages and distribution into puzzle creation means that they can't be perfectly tuned for all players, so the goal is to tune the puzzles to fall into that optimum range between easy and difficult or bored and frustrated so that players can concentrate and at least move towards a state of flow.

Finally, we also wanted our players to feel immersed in their experience. Immersion is defined for our purposes as the action of drawing players into the world of a game and making them feel like they are a part of the story being told. It's a feeling similar to nostalgia for an experience that a player hasn't ever had before, like an incredible memory that they get to engage in live. Not all games utilize high levels of immersion as a tactic in their arsenal, and one of the reasons that some escape rooms in particular shy away from a more intense experience is the concern of overwhelming players in a physical space that surrounds them. Since players would only be able to interact with our room through the robot via a web page, there is an added layer of distance not normally present in escape rooms, meaning that stronger theming and immersion on the story's behalf made sense for the experience. Immersion also plays back into engagement when used properly since further investment in the story, characters, and environment can make players more invested in their conclusion (Stuart, 2010). Since the location of play for this project doesn't involve actually locking players in a room to create a sense of urgency, we bolstered that feeling with an increase in theming and the associated immersion.

Ultimately, our experience goals became broad guides for how we were going to work through our design process, and led us to make many of the decisions we made for the narrative and mechanical design of this interactive experience.

5.1.4 Designing for the Robot

Unlike most escape rooms, which can be a series of puzzles with no gameplay elements in common, our escape room has core mechanics tied to something outside of the gameplay element. This is because every challenge in our experience must be engaged with through the robot. Similar to a playable character which one would control in a video game, the robot is an avatar with a limited set of abilities. It is impossible for players to perform any action which isn't built into the robot and web interface, so they will rely on those same abilities for all challenges throughout the escape room.

Gameplay challenges cannot be designed without an understanding of our core mechanics, which suggests that robot design comes before puzzle design. However, the way the robot should be designed is dependent on what it will need to do, which suggests that puzzle design needs to come first. Gameplay design and robot design involve different disciplines being handled by different people, but their development is deeply intertwined. Neither can simply be completed before the other. This is where circular iteration comes into play. Our game designers and robot designers needed to be in close communication, ensuring everyone had the same understanding of the other group's design, moving through multiple different iterations of each concept as it's passed back and forth between teams, evolving as it goes. This process is not without its flaws and difficulties, especially considering the particular challenge of having members who work in multiple different fields. People working in different fields will naturally have different perspectives, which often requires concepts to be translated across disciplines, leaving room for misinterpretation. This meant that communication would become more difficult but even more crucial to success. Luckily, because circular iteration involves continually circulating a concept between teams, a breakdown in communication could be discovered and addressed during later iterations and fixed by adding a few more cycles to the process.

5.1.5 Modular Design

Building off of last year's project, the previous team had utilized a modular design base for this remote escape room. They had created a set of wall and floor tiles which could be fit together like puzzle pieces in several different ways in order to build their initial room. However, when it came down to assembling the space and printing the pieces, it became clear relatively quickly that these designs weren't as modular as we thought. While many of the designed pieces have the capacity to be rearranged if necessary, this would require that the pieces be able to mirror reverse which side of them was towards the inside of the room, the reason being that the design of the pieces was, again, sort of like puzzle pieces: with one section that sticks out and plugs into the cutout of another section. All pieces had the ability to flip direction, until a vinyl plastic layer was placed over their final configuration such that the vinyl sides needed to be faced inward towards the room. Without the ability to flip pieces, it's like putting together an actual puzzle; most pieces had a place where they needed to be and there wasn't much wiggle room for moving those pieces around the space because of how the surrounding sections were constructed. This issue also would've been further exaggerated if we had ended up printing any designs on the laminate, forcing every tile to be even further solidified in their space. Thus, pretty early on in our process we had to make a decision: what level of focus did we want to put on prioritizing modularity?

Almost immediately we ruled out the possibility of having the experience we were designing be a fully rearrangeable one. There was some consideration of the potential to have puzzles which could be moved within the modular space so that the setup of puzzles could change from playthrough to playthrough, but it was halted after realizing that the previous year's work had created a room which largely could not be built in more than two configurations (and even between those varying assemblies there was very little difference in the ways players could interact with the space). However, the framework files which show how the tiles are cut and how they fit together was explanatory enough that we were able to manipulate the tile design files to create the space that we wanted our players to be able to explore. With these factors in mind, we knew it would be unlikely to create a room where everything is modular immediately, and that there would likely not be meaningful rearrangements for the puzzle placement in the rooms even if we designed for multiple different puzzle placements. Thus, the focus became to create one very good story which played through in one way without utilizing the modularity of the room in the design. Instead, modularity became a tool for thinking through the framework of our game space, where the modularity of the room setup allows for the same development tools to be used to create multiple different stories with the same base system. Our focus was on creating a story experience within a set space given a solid foundation to start from.

The idea of a modular system but a fixed experience was further solidified as we continued to iterate, leading to several key changes. The first change we made to the base system was to ensure that modularity could create a non-square room. During Alphafest playtesting, it was identified that players had a difficult time navigating the space when all of the room walls were of the same length, as it created a very monotone environment and it became difficult to remember where room props and puzzles were located in reference to the space. Next, we had identified that many escape rooms have multiple different spaces to play through. Thus, to create a more full experience reflective of that paradigm we wanted to have the players move from one space to another, which meant accounting for a door. These two changes to the original modularity required iteration between the game design and room design teams, which resulted in the decision that the space worked best when puzzle locations were predetermined and not to be shifted around the space. Thus, the final adjustments to the modularity of the space were to ensure that each individual room tile can accommodate for a space that isn't perfectly square, ensuring that there was the possibility for more than one space to be connected. We decided to use modularity as a foundation to build other games up from, rather than utilizing the modularity as a function of the game design itself. This became a base for how we needed the puzzles to exist within the room, which narrowed down the types of designs to ones that we felt fit the best within this framework.

5.2 Playtesting

In this section, we will discuss the numerous iterations that were made along our design process, starting with several ideas which did not make the final design and why they were removed. Next we will talk about the specific playtesting we did and how feedback changed our designs.

5.2.1 Design Iteration

Many of the puzzles were scrapped or heavily revised due to the need to simplify game mechanics or because they would not work well in tandem with the robot, many of which are outlined in Appendix C. Since the player would already have to interact with these puzzles through their imperfect control of the robot, the puzzles themselves would need to be more straightforward than a typical escape room.

One of the first puzzles we removed came from our initial draft of puzzles proposed to the robotics team. This puzzle, which we simply dubbed "the map puzzle" (see Appendix C), involved having players place objects on sensors located throughout the room based on a map which they would be able to see on one of the walls (Figure 13).

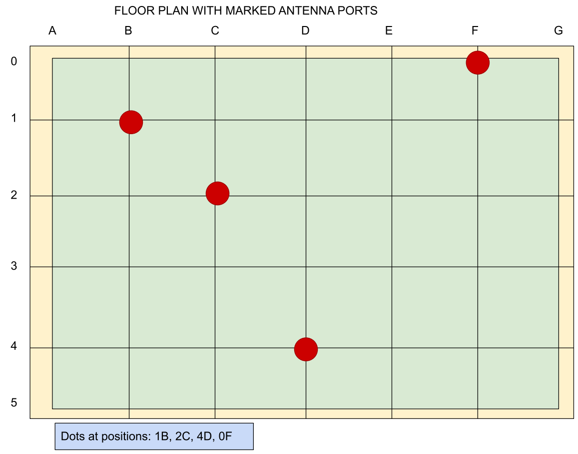
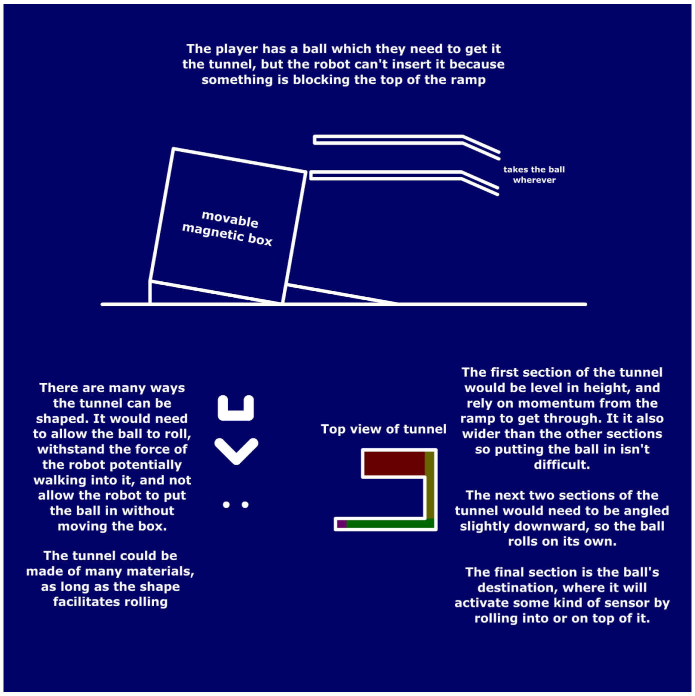


Figure 13: Map Puzzle

The initial plan for this puzzle was to have an antenna which needed to be situated in the ground based on the corresponding points within the map, with only some of the marked spots being important based on coordinates elsewhere in the room. However, we quickly discovered through playtesting that participants would often get lost within the small space, due in part to the format of their vision through the webpage. We then realized that this puzzle would need to undergo massive reconstruction to suit the needs of the players. We approached the idea of including a minimap on the webpage which tracks the robot, which the players could use to determine exactly where they are in the room in comparison to the map. This proved challenging however, as it meant passing a significant number of signals between the room, robot, and webpage and dealing with any potential lag that might confuse the players. Ultimately, we decided we would not have enough time to implement this solution, and that our time was better spent investing in other puzzle concepts that better worked with the robot instead of against it.

Another of the puzzles we removed was so elaborate that we unofficially called it a rube goldberg machine (Figure 14). The player would need to find a magnetic box and a small sphere in opposite corners of the room, and carefully position them on a sloped surface in order to facilitate the ball rolling into a thin tunnel. The diagram below describes how the entire setup would have worked.



The player has a ball which they need to get it the tunnel, but the robot can't insert it because something is blocking the top of the ramp

There are many ways the tunnel can be shaped. It would need to allow the ball to roll, withstand the force of the robot potentially walking into it, and not allow the robot to put the ball in without moving the box.

The tunnel could be made of many materials, as long as the shape facilitates rolling

The first section of the tunnel would be level in height, and rely on momentum from the ramp to get through. It it also wider than the other sections so putting the ball in isn't difficult.

The next two sections of the tunnel would need to be angled slightly downward, so the ball rolls on its own.

The final section is the ball's destination, where it will activate some kind of sensor by rolling into or on top of it.

Figure 14: A blueprint for how the “rube goldberg” puzzle would function

The idea above would have been functional in theory, but it had an overwhelming number of distinct elements. The ramps, the tunnel, the sensor at the end, and the two movable parts would all need to coalesce. We would have to carefully tune a physics-based puzzle to work reliably, the player would need to recognise the specific arrangement in which these pieces can interact, and they would have to set up that interaction with a fair amount of precision. This concept may have been suitable for a full-size in-person escape room, where both designers and players would have perfect control over how they use the objects at their disposal, but was far too intricate given the constraints of our project. Building for chance wouldn't work, and as we iterated through these puzzle versions we also slowly began to better understand how to design for the robot itself, since we weren't working in a game engine for this project.

5.2.2 Protofest

Protofest and Alphafest were the first times we got the opportunity to meet and test with potential players. Protofest in particular was the first time we needed to explain in an elevator pitch style exactly what we were building, and get feedback on whether the game plan would be interesting for players. To do this, we created a slideshow presentation of our plan, brought a version of the robot, and set up a table in preparation for user feedback. During the event, we explained to players our game design intentions and the existing systems and asked whether those seemed like concepts people would be interested in playing with. We all reviewed the suggestions and feedback together to find if there were any angles we might potentially be missing. From this data, we were able to identify that players were excited by our theme and the ability to play with a robot, but were not entirely convinced of the vague disaster scenario we had proposed. By this point, we had not fully fleshed out the entire adventure, as many of the puzzles still required narrative weaving, and as such the description of the story we gave was extremely limited. This limited narrative explanation left players wanting, and one suggestion we were given was to create a shift partway through the narrative where events "take a turn for the worst." The idea was that every good action drama experience has a moment where they reveal that the problem is worse than originally thought, which we would be able to replicate in some way with our puzzles to further create an atmosphere of urgency in the space without panicking players.

We had several potential ideas for how we could create this moment: the first of which involved having a moment where asteroids hit the ship and knock more things out of place only to cause further issues, another of which involved resetting the existing puzzles with new inputs in some way, or potentially we thought of having parts of the room destroyed. Ultimately, the way that we approached that idea was in the reveal of our second room, when players would discover exactly how much more there was to do, in the same way that flipping over a test only to find the back side forces a student into crunch mode. This way, we would have the effect of added urgency that comes with realizing time is running out and there's still so much to do, but without creating an event out of the scope of our space. This, along with some small tweaks in narrative direction, put us on the track to create the product we displayed at Alphafest.

5.2.3 Alphafest

By the time we came to Alphafest, we had rebuilt most of our first room and had designed the puzzles that would be tested with a large pool of playtesters. The plan for this was to test the Simon Says puzzle we had designed and the exit door puzzle. Both of these only existed within the first room, which was the room we had decided to focus our testing on. However, we started running into issues with the robot interacting with the wifi as soon as we set up. With so many devices running and pulling resources in one small space, the lag between our robot controls and the camera view of the room was nearly 30 seconds, almost impossible to test with. As a result, we resorted to an older form of playtesting: a combination of paper prototyping and Wizard of Oz testing. Paper prototyping is a kind of paper testing where designers of a product write things that would normally be digitally coded onto pieces of paper instead, and then manually move those papers as the user interacts with them to inform their experience as intended (Fullerton, 2018). Wizard of Oz testing is a type of testing which is relatively similar, but it involves having players interact with a system without knowing that it is being controlled behind the scenes by a human operator instead of the machine being tested (Harwood, 2018). Combining the two, we ended up with a system that had players sitting in front of a screen which was connected to a cell phone camera being navigated throughout the room by an operator, though our players were aware of the human operator (making it only partially Wizard of Oz style). Playtesters would then shout out what commands they wanted the robot to do (which were written on a control panel at the player's disposal) to the operator holding the phone camera, who would then navigate as instructed (Figure 15 and 16). Unfinished puzzles were modeled using paper prototyping methods, and users would also interact with them by shouting commands available through the control panel. In this particular case, there were paper prototyping elements to represent room panels, things written on the walls, scannable codes and blinking lights. On the player end, there were paper prototyping elements in place of pop ups including a password popup, an error popup, an incorrect password popup, and popups for other website behavior.

Figure 15: AlphaFest

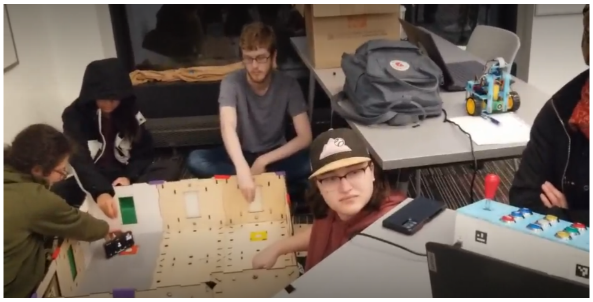


Figure 16: AlphaFest

Through this playtesting method, we were able to glean significant data about the ways that players interacted with our room. Included in that data we discovered that:

1. Our Simon Says panel key was frequently mistaken for a stop light and confused some players for significant amounts of time.

2. Having the password puzzle be as simple as locating the puzzle written in blacklight was a bit of an anticlimax, but the idea was favorable.
3. Not all players immediately knew what a blacklight was and therefore did not know when or how to use it.
4. Players got confused when there were different controls for moving the camera and moving the robot.
5. Our screen was too small to see enough of the room, which often left players disoriented.
6. Players without a background in IMGD approached the room very differently from game development students, encountering different stopping points and confusions.

With this information, we made adjustments accordingly:

1. By changing the Simon Says puzzle to have the lights blink one at a time, only lighting up to blink on the next panel after the previous one was set to solid, we eliminated the need for the confusing stop light panel.
2. Our password puzzle evolved to become a word unscramble with multiple different colored letters, allowing players to do more than spot the blacklight answer.
3. Adding an explanatory page on the website was our solution to players not understanding the controls and what they do- particularly the blacklight.
4. We eliminated camera control other than for looking up and down so that the camera is always facing the direction the robot will drive.
5. By replacing the camera on the robot we were planning to use (which was fairly well mimicked by the cell phone camera) with a fisheye lens, players will be able to see more of the room. We also changed the dimensions of the room so that they would not be

square (which was the previous year’s design) to further distinguish the different areas of the room by decreasing sameness.

6. Testing with non-IMGD players allows us to see how other minds think when interacting with our puzzles, so further playtesting made efforts to test with students from other departments as well as game development students.

Thanks to this combination of collected data, we were able to find information not only to improve our game, but also the design and testing protocol we were following at that point, which helped us make the necessary adjustments to continue onto our next phases of iteration, implementation and testing.

5.2.4 Playtesting Phase 1 (C-Term)

In the time from February 21st to March 2nd, we had several playtesters try out the escape room using a Wizard of Oz paper prototyping method for the puzzles we had at that point. This escape room was made mostly of paper prototypes, and no robot to interact with them. Our “robot” was a phone camera being held and manually moved around the room. Meanwhile, the playtester would view the room on a laptop via zoom and control the camera by shouting instructions at the project member holding it. This made for an experience which barely resembled what the final product would become, but we were still able to get some valuable feedback about the design of our puzzles (see Appendix B). Here are the most notable problems we encountered in this playtesting period:

1. The blacklight was too small and ineffective to light the entire password puzzle at once.
2. Immediately upon starting the experience, players would often step on the red light sensor of the calibration puzzle unintentionally.

3. In earlier phases, players had to read symbols on one side of the room while standing on the opposite side. Playtesters often had trouble reading the symbols from a distance due to the resolution of our camera.
4. The laser-cutting puzzle was unintuitive. Players would see the blank page on the wall and have no idea how to interact with it.
5. The original wire connecting puzzle (Figure 17) was too easy. All of our play testers immediately knew what to do and executed the solution with no difficulty.

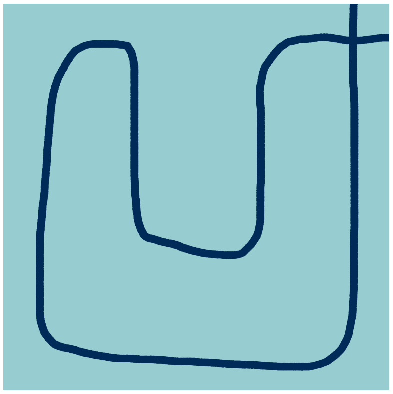


Figure 17: First iteration

6. The box-pushing puzzle was too complicated (Figure 18 and 19), players would get to the answer by blind trial-and-error, or not at all.

Figure 18: Paper box slide

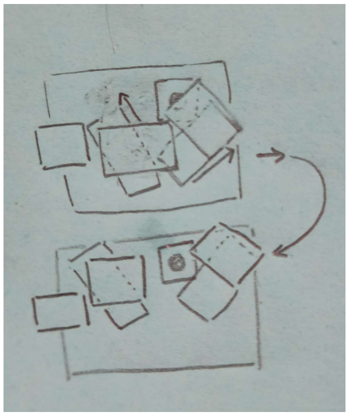


Figure 19: Box slide brainstorm

7. Players did not realize they needed to use the blacklight to read the hidden message written on the signal tower table. Players thought to use the blacklight on every piece of paper in the room, but not the table.

The changes we made in response to these issues when they were identified are as follows:

1. We wrote the letters of the password much closer together and on a smaller piece of paper, reducing the need to light a large area at once.
    a. We invested in a more powerful blacklight for the robot.
2. We deliberately changed the robot's starting location to be further from and facing away from the red light corner. This meant they would be unable to step into the red corner without seeing at least half of the room, and getting to grips with the robot's movement.
    a. We also added large colored squares on the floor by each of the three lights. This lets the player know that there is significance not just to the lights on the wall, but to the area of ground immediately in front of them.
3. We rewrote our narrative such that the player would be able to get closer to the symbols. Instead of having the robot be afraid of the dark and unable to enter the room, the robot was stubborn and unwilling to perform tasks involving the arm. This successfully

controlled player progression in the way the original setup did, while solving the issue of players being unable to read faraway text.

4. We recontextualized the puzzle to be about removing screws instead of laser-cutting. This allowed us to draw screws on the corners of the paper, cluing the player in on how the puzzle is to be interacted with.
5. We added complexity to the visual design with incidental details. The final version (Figure 20) has extra wires which are not relevant to the solution, but make the puzzle more visually interesting, and in turn more difficult to solve.

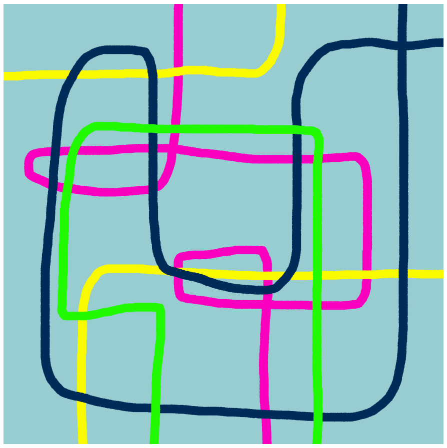


Figure 20: Second Iteration

6. We removed one axis of movement for the boxes. By including fewer ways to interact with the boxes, it became easier for the player to deduce what interaction needed to happen.
    a. We also removed the constraint that they be pushed in a specific order. Our playtesters would often push a box earlier than they were supposed to, and assume the box was unimportant when nothing happened.
7. We decided to add paper stars on the walls. These stars would be outlined with a blacklight marker. There would be a cluster of these stars on the floor surrounding the

signal tower table, making the player much more likely to shine the blacklight over that area and see the hidden password.

5.2.5 Playtesting Phase 2 (D-Term)

By this point, the experience which we were able to playtest was radically different from what we had been doing in previous terms. We had a robot with a camera and lights which users could operate themselves via keyboard. The website was also functional, having an interface which included the opening narrative, hint tree, pop-ups for specific puzzles or password inputs, and all controls needed to complete the first room.

Due to time constraints, we were unable to get as much playtesting data in this period. The processes of building our robot and establishing successful communication between the robot, room, and website continued into the time period which was planned to be reserved for play-testing and writing the report. However, we still received feedback which allowed us to polish our experience. Our website and user interface were now available for users to interact with, and we got suggestions for improvements such as making the control scheme visible on the main page, or changing the colors of certain icons in order to make them easier to see.

6. Website

The website was designed to be the connection between the physical escape room and the robot. The website is the only part of the escape room that the player physically touches and directly interacts with. The robot and room are both connected to the website using Message Queuing Telemetry Teleport (MQTT), which is a wireless network protocol that is designed for sending light-weight messages between devices. MQTT uses a publish-subscribe system that allows the website to both send and receive messages from the robot and room, respectively.

The robot's camera feed is streamed to the website, allowing the player to remotely control the robot based on what they can see through its "eyes". The keyboard of the computer displaying the website is not connected via MQTT, since we discovered that there is less input lag using a bluetooth keyboard than using MQTT. The website sends a message to the robot at the beginning of the game that allows it to begin moving. The robot sends messages to the website when it reads an ArUco marker, and the robot constantly sends messages denoting which of its features are on and which features are off, such as the light, the black light, and the magnet.

The room also sends messages back and forth with the website. The room needs to tell the website when each puzzle is complete, so the website knows which hints to display, should the user ask for help. The room also needs to tell the website how far along the robot is in the room, so the website knows when to play certain sound cues and voice lines. In return, the website also needs to send messages to the room. The room needs to know once the player has started moving the robot, so the first puzzle can begin. The website also tells the room if the password it received was correct, so the room knows to open the door. Finally, the room needs to know when to turn the lights on, after the player has completed the third puzzle, and reactivated the lighting system.

We knew that the main page would be where the user spent the majority of their time on the website, so we began with making mockups for the main page. We chose an initial color palette that we thought worked well with the outer space theme we initially designed for our escape room. As seen in Figure 21, we started with the features we thought were the most necessary, such as the camera, a minimap, which features of the robot were on and off, and a hint bubble. We ultimately settled on the leftmost design in Figure 21 for our main page.

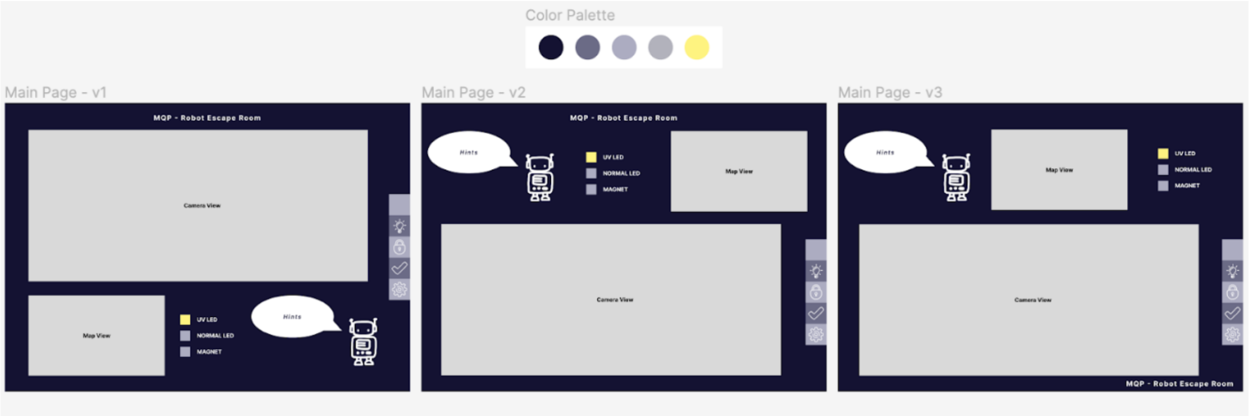


Figure 21: Initial Designs for Main Page

We wanted the website to be an integral part of the escape room experience, and have more than just a main page. We wanted the player to have other pages to explore, so we came up with some ideas for additional pages that we wanted. These pages were a password page, a progress page, and a settings page. We included their icons on the navigation bar on the side, in addition to an icon for the hint button. We also created an initial mockup for each of the three additional pages, as shown in Figure 22.

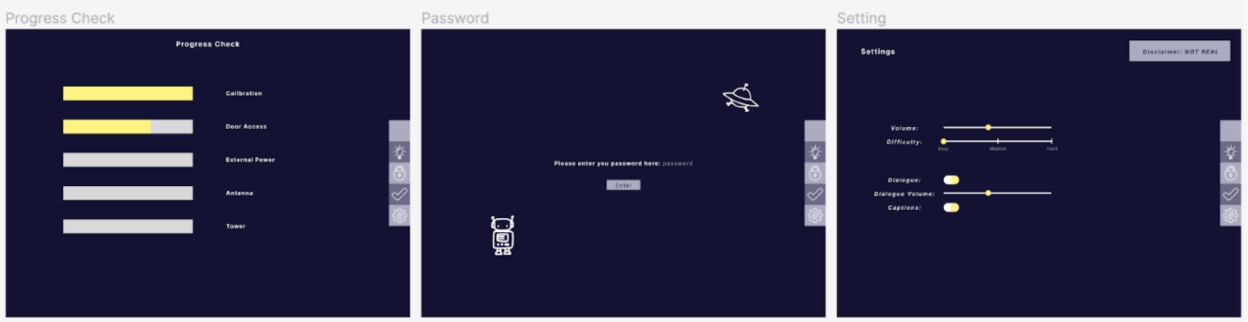


Figure 22: Initial Designs for the Progress Page, Password Page, and Settings Page

As highlighted in other sections of the paper, circular iteration was fundamental throughout our project, and the website was no exception. Throughout the months we spent working on this project, the designs for the website changed constantly, and features were added and removed. The first change was to simplify the main page. As shown in Figure 23, we decided to remove the minimap and which features of the robot were on and which features were off at any given moment. While we believed the minimap would have been a useful resource to have on the website, we ultimately ran out of time and had to prioritize other features of the room instead. The gray box in Figure 23 denotes where the camera was designed to go after we had cut features and simplified the view. The hint bubble was removed during this stage of design, as we were planning on having the hints be on a separate page.

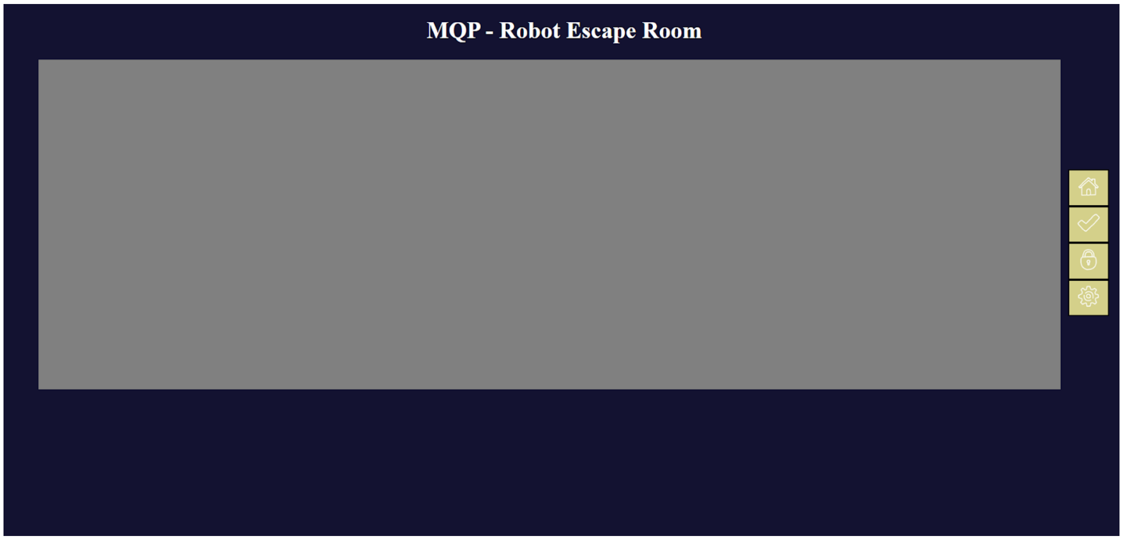


Figure 23: Intermediate Design for Main Page

Due to the constraints of the camera, we had to shrink the size of the camera view from what we intended it to be. However, this gave us more room to work with on the main page, so we added the hint button back, and also made room for a website puzzle, which is part of the third puzzle in the room.

Figure 24: Final Design for Main Page

We also redesigned the hints again, leaving a hint button on the main page, but also giving hints its own page, as shown in Figure 24. Since we have so many different hints, we were concerned about players viewing a hint and then forgetting it, and wanting to reuse the hint; because of the existing hint button mechanic, which would pop out a new hint each time it was pressed, we needed another way for players to view the hints they had already unlocked. Therefore, we designed a hint page, where the user can review all of the hints they have already received (Figure 25). If the user has not already used that hint on the main page, it will show up as locked on the hints page. We also added more webpages in, such as a manual page, and an introduction page, shown in Figures 26 and 27, respectively. We added the manual page after playtesting results showed that some players did not know what a black light was. We added the introduction page to give the user more backstory into why they were in their current situation and why they had to remotely control a robot, versus making the repairs themselves.

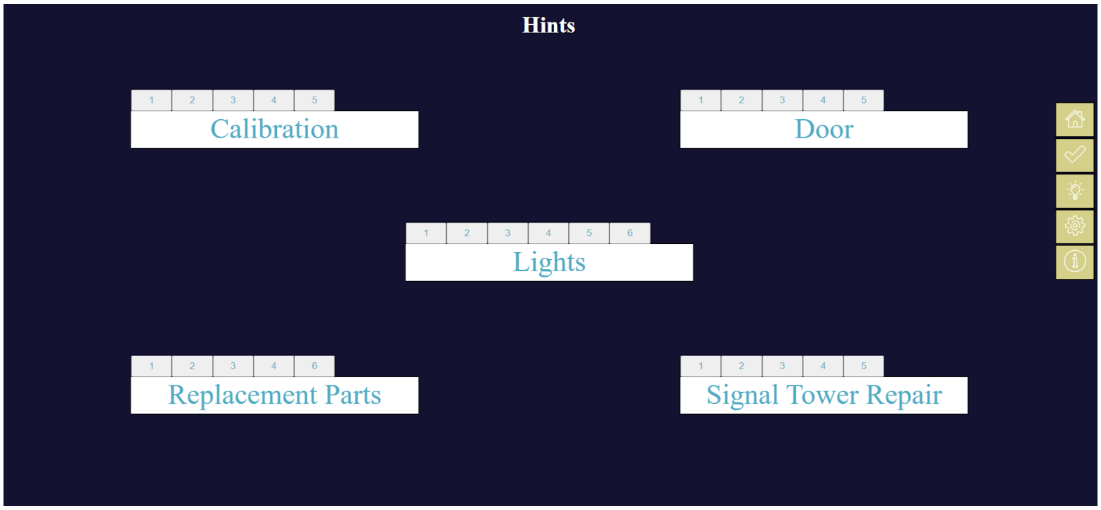
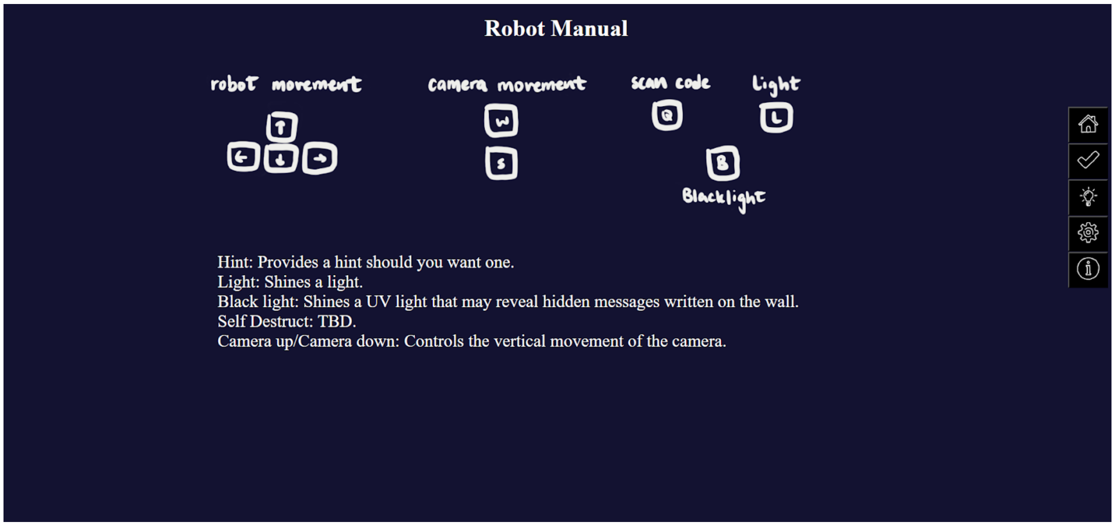


Figure 25: Hints Page


Robot Manual

Hint: Provides a hint should you want one.
Light: Shines a light.
Black light: Shines a UV light that may reveal hidden messages written on the wall.
Self Destruct: TBD.
Camera up/Camera down: Controls the vertical movement of the camera.

Figure 26: Manual Page

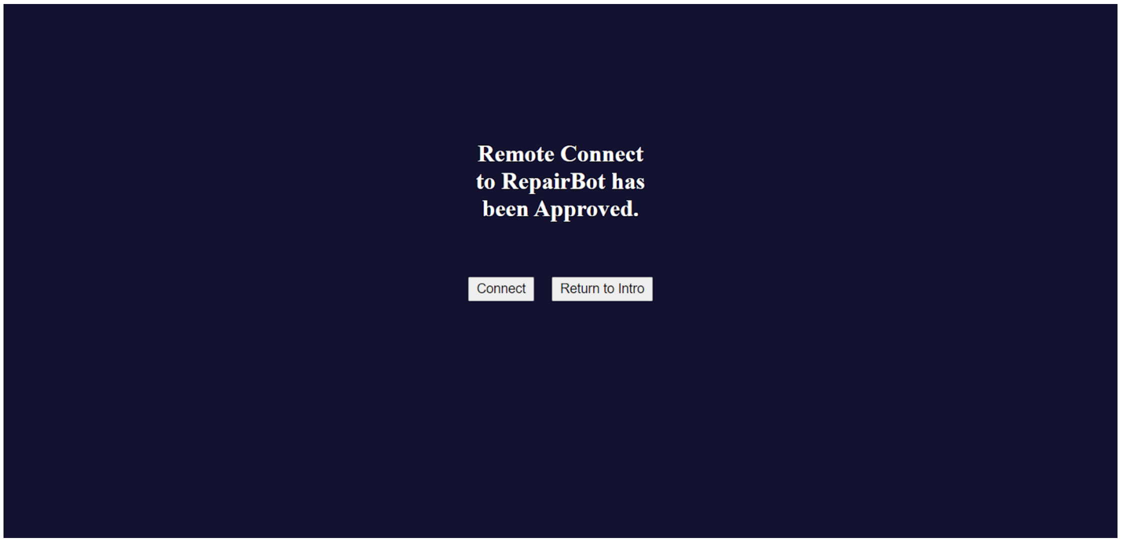

Remote Connect to RepairBot has been Approved.

Figure 27: Login Page

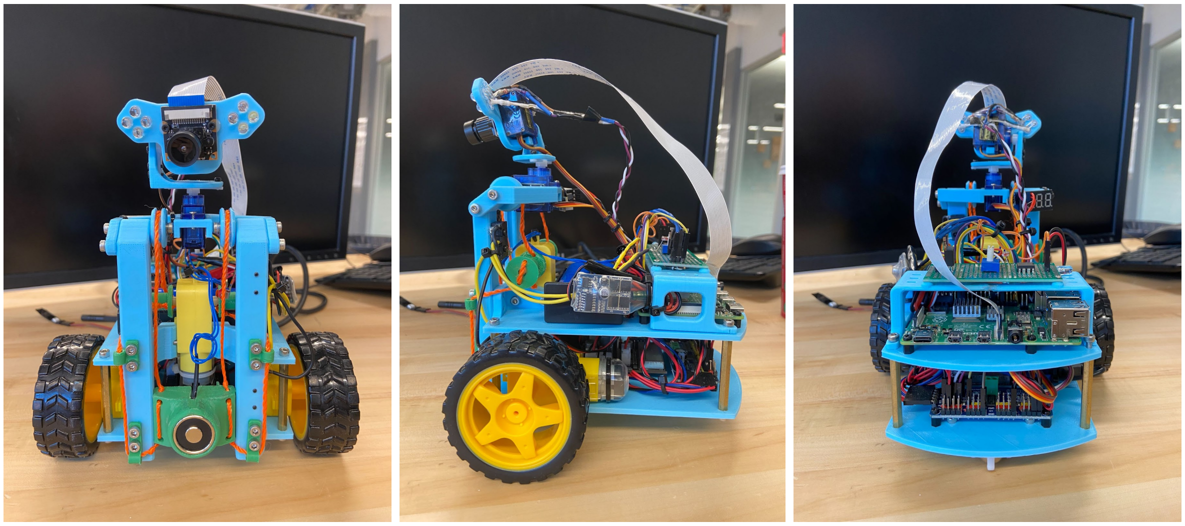
7. Robotics Design Methodology

In this chapter we first talk about our design process starting from where last year’s team left off. Following this we present the final design of the robot, its arm and other components. We then explain how the robot was adapted to fit our new requirements and goals for this year. An explanation of the wiring and coding of the robot and its components follows. The room design is then explained in detail starting from where last year’s team left off and adapting this to fit our needs for this year. An explanation of the manufacturing process and wiring and coding of the room follows.

7.1 Last Year’s Robot Design

The design from the 2021-2022 Robot Escape Room MQP (last year’s team) provided our team with a head start and offered ideas on how to design our robot. We will provide some details about last year’s robot and then focus on our decision to create a new robot rather than building upon the previous design.

The robot shown in Figure 28 was created by last year's team to meet several design goals. These included the need for reliable construction to prevent failures, a mobile base for maneuverability, a small size for better maneuverability, a manipulator for interacting with the environment, a controllable light to illuminate the robot's view, a camera for video streaming, and enough battery life to complete all puzzles.



Front View *Side View* *Back View*

Figure 28: Robot Design from 2021-2022 Robot Escape Room MQP

As depicted in Figure 28, the robot was implemented with two layers. The first layer housed the motors and motor driver, while the second layer accommodated the Raspberry Pi, batteries, and custom PCB. At the front of the robot was the lift with an electromagnet acting as a manipulator for puzzle-solving, and on top of the lift sat the camera and lights.

Following an initial brainstorming session with our team, we identified several issues with the previous robot. The batteries lost power too quickly, the circuits were disorganized, the camera angle was not user-friendly, and the robot's features did not entirely meet our desired specifications. Furthermore, we concluded that a round-shaped robot would be more advantageous for our purposes.

Based on our assessment, we decided that creating a completely new robot was the best approach to address the aforementioned problems. By starting anew, we could take a fresh approach to the design, incorporating the necessary improvements while ensuring that the robot would meet our intended specifications.

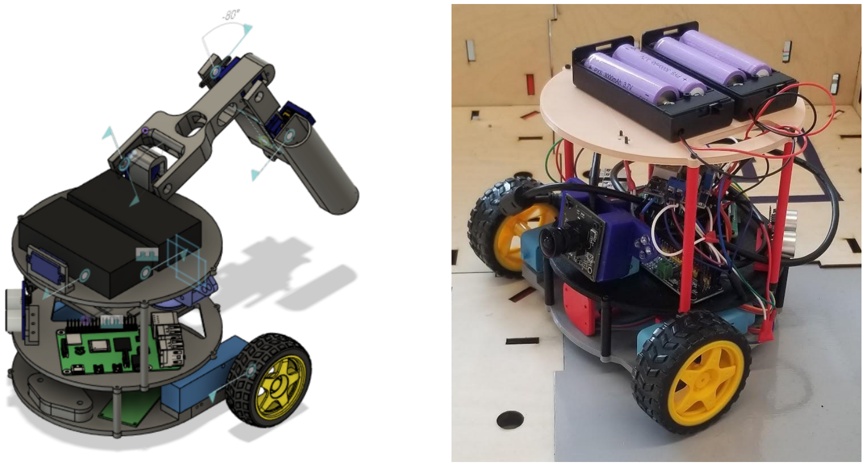
After playtesting at Alphafest, we discovered that the batteries did not last long enough. During our brainstorming session, we decided to include five puzzles in our escape room. However, when we attempted to present our paper prototype to participants using last year's robot, the robot "died" before completing the first puzzle. The batteries had a very short lifespan, and it took too long to charge them. To solve this problem, we needed a better power source.

The camera view provided to the players was also inadequate. Last year's robot had a standard CSI camera that did not offer a wide-angle view, making it difficult for players to see what they needed to see. This could lead to control issues and could prevent players from successfully escaping the room. Additionally, the rectangular shape of last year's robot made it more likely to get caught in corners and become unbalanced. To address these issues, we decided to create a round-shaped robot system. This system allowed for better maneuverability, a balanced distribution of weight across both wheels and fewer chances of getting caught in corners. In addition, the lift was located directly below the camera, restricting the player's view of what they were picking up.

Furthermore, last year's robot features did not meet our specific puzzle goals. We wanted to change the wheels to have encoders, add an arm for more human-robot interactions, and include a rangefinder to prevent the robot from hitting walls. With encoders on the wheels, we could display a mini-map on the website and improve the overall control of the robot. Combining the idea of a confined view with the lift, the arm allowed for more functionality than a simple lift manipulated by a string, making it easier for players to see what they were picking up when properly positioned. Additionally, the cable management from last year's robot was also disorganized and hard to monitor. With these considerations in mind, we concluded that scrapping last year's design and starting from scratch was the best course of action.

7.2 Final Robot Design

We designed the robot to have 3 circular layers that collectively hold a Raspberry Pi 4 Model B, a motor controller, an electromagnet controller, a servo controller, batteries, two front situated driving motors with encoders, a rear castor wheel for stability, a fisheye camera on a vertical servo mount, a range finder, and arm with two degrees of freedom with attached electromagnet and end gripper. Throughout the layers there are holes for ease of cross level wiring (Figure 29).



Model in Fusion 360 *Final Robot in Room*

Figure 29: Final Robot Design

On the top layer we situated the battery boxes for ease of access to the batteries, situated in the rear of the bot to counter balance the weight of the arm (Figure 30). The arm is placed on the top level of the robot so that it can have a greater range of motion than it would if it were placed on one of the lower levels. It is located on the front right of the robot so that it can be in constant view of the camera without taking up the player's entire view. It was designed to pick up (in-game) broken signal tower parts, manipulate an environmental block puzzle, and manipulate the electromagnet to navigate two wall puzzles that ask the magnet to move up and down to various heights.

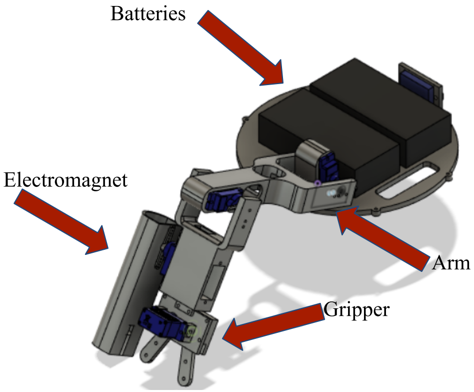


Figure 30: Top Layer of the Robot

On the middle layer there is the Raspberry Pi board, the servo controller board, a camera with a fisheye lens mounted on a vertically rotating servo, and a rangefinder situated facing a 45° angle off of the left of the rear (Figure 31). The fisheye camera mount is mounted to a servo to give the players the ability to look up and down, further increasing player sight. On the camera mount there are also white LED and blacklight LEDs to allow players to solve several blacklight puzzles as well as see in the dark second room. Having the LEDs mounted on the same servo allows the light to follow the player view, making it easier to solve puzzles as well as a more natural experience. The servo that controls the vertical orientation of the camera and the ability to power the LEDs are controlled by player input. The camera itself had a fisheye lens to increase player vision and also has the ability to scan ArUco codes.

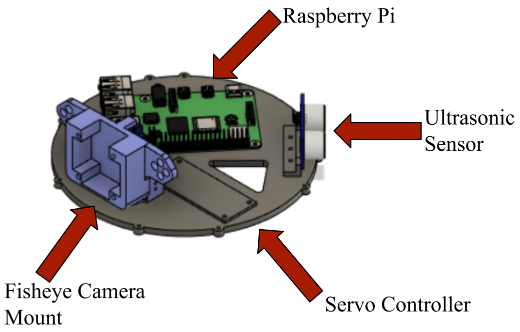


Figure 31: Middle Layer of the Robot

The bottom layer is composed of our motor controller, electromagnet controller, our two driving motors, wheels, and our rear castor wheel (Figure 32). The wheels and electromagnet are controlled by player input. The motors have encoders, which, when combined with the rangefinder, and camera, would allow us to know where in the room the robot is. However, due to time constraints, we were unable to get this feature operational. Our rear castor wheel provides stability.

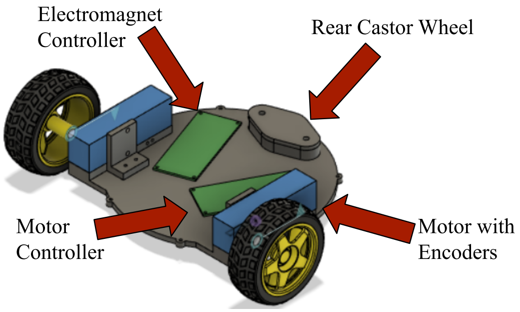
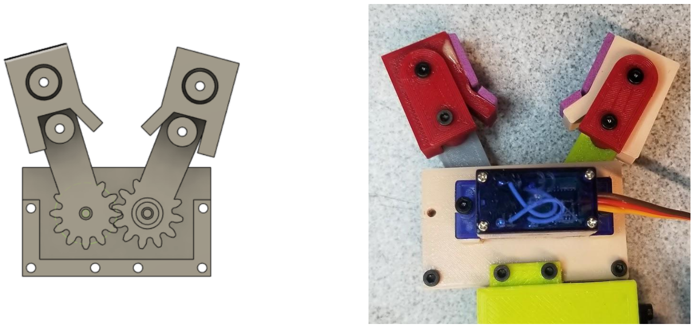


Figure 32: Bottom Layer of the Robot

7.3 Robot Development

As stated above, over the course of this year we redesigned the robot entirely. In this section we will go into more detail about the designing of the gripper, the arm, how the robot was wired, and the implementation of the robot's code.

7.3.1 Robot Design: Gripper



Model in Fusion 360 *Final Gripper*

Figure 33: Final Gripper Design

This year we knew that we wanted the robot to be more dexterous and offer a different way for the robot to interact with the room, in turn allowing for a different variety of puzzles to be developed. While we considered a variety of interaction mediums we ultimately settled on an arm and gripper (Figure 33). Due to the tightly coupled nature of the gripper and the game design, we delayed the development of the gripper until we knew the constraints dictated by the puzzles.

Once we had an outline of the puzzles in development we started by assessing different styles of gripper. When comparing a claw gripper to a parallel jaw gripper, we decided to design our gripper to be a claw gripper. A parallel jaw gripper, in order to get a firm grip, requires the user to have a lot of precision in its operation. As the player is unlikely to have worked with robots before, let alone have the expertise needed to operate a jaw gripper well the first time under the pressure of a time constraint, we decided to focus on developing a claw gripper. A claw gripper is more forgiving to work with by allowing puzzle objects to be placed at less exacting points than a parallel jaw gripper would necessitate. A claw gripper also has a lower profile design so the player will be able to see what they’re doing better.

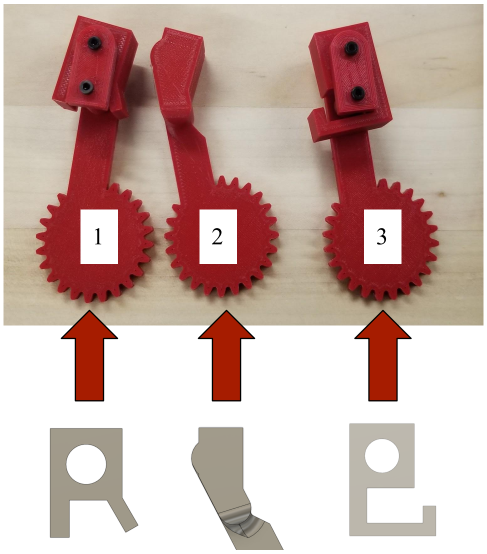


Figure 34: Gripper Tip Variations

Once we decided on a gripper style, we iterated on the grip tips. By this point, we had set puzzle object geometries for what needed to be picked up: a 19mm x 19mm x 19mm cube and a regular hexagonal prism of similar dimensions. We experimented with 3 different designs. Design 1 in Figure 34 features a freely rotating “R” shaped gripper tip that was designed to be flush to the flat planes of the cube and prism, as well as the corners of the hexagonal prism. Design 3 is a similarly designed freely rotating “g” shaped tip. Design 2 is a fixed design. We decided that Design 3 was ultimately the design we wanted to work with due to its more flexible nature when compared to Design 2 and its less bulky design when compared to Design 3.We decided to increase friction on the finger surfaces in order to grip objects better by adding foam gripping edges of the grip tip.

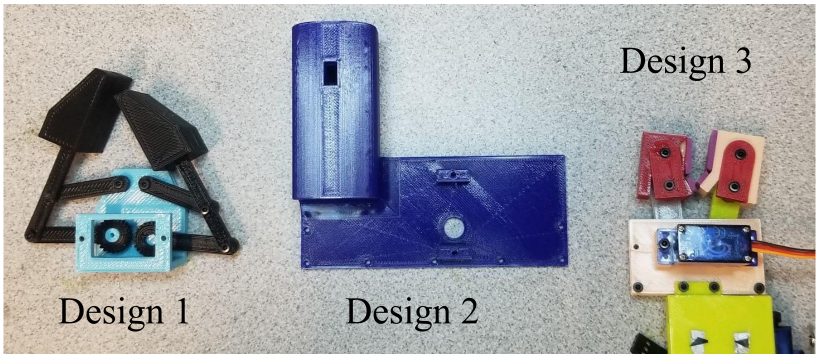
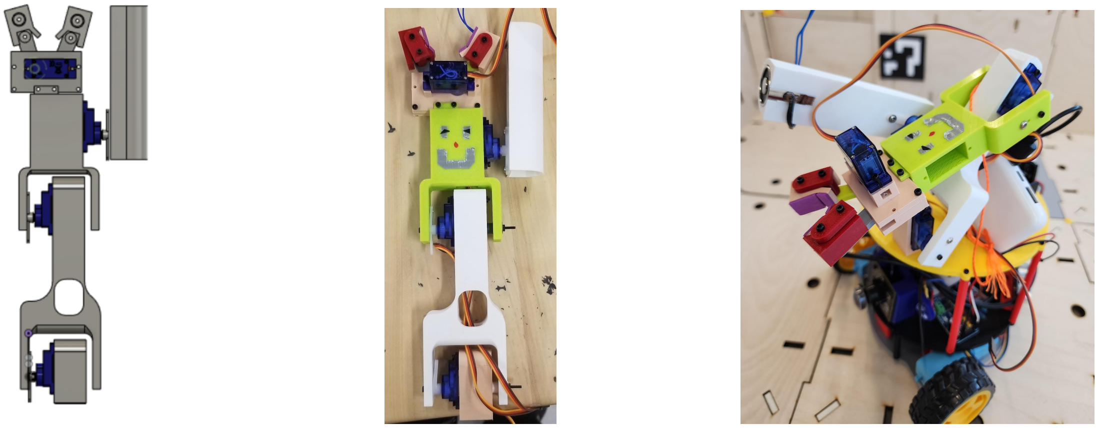


Figure 35: Gripper Design Iterations

We went through a few different sized grippers. Our first design (Design 1, Figure 35) was a very good jumping off point, however it was too small to fit the controlling servo, and too did not articulate in the way we needed to be able to articulate in order to pick up our puzzle objects. We then sized the gripper too large (Design 2, Figure 35). We knew that the puzzle objects we would have to pick up were light, but in an effort to accommodate for future iterations we thought it best to have a gear ratio that increased torque. We also added a spot to hold the electromagnet on this larger version. However, once assembled, we found that the large gripper was approximately half the robot's height and that it would likely cover the majority of the camera (and therefore the player's) vision depending on arm lengths. We knew we had to downsize the gripper severely.

For our current iteration, Design 3 as shown in Figure 35, decided to lessen the gears and went from two 24 tooth gears connected with 12 tooth gears, to just two 12 tooth gears. This change allowed the new gripper to be approximately one quarter of its previous size. Going from the large gripper to the new small gripper we also realized that while it was important to have the magnet be able to reach out further than the gripper to maximize the magnet's strength, if the magnet was longer than the gripper could reach, then it might become very difficult to pick things up with the gripper. To achieve both size and usability constraints we decided to move the electromagnet to the arm. While the geometries have been tested and the gripper does fit the cube and the prism, the system has yet to be powered and tested.

7.3.2 Robot Design: Arm



Model in Fusion 360 *Arm printed and assembled* *Arm attached to robot*

Figure 36: Arm Design

We chose to design an arm this year to increase the options for potential puzzles by increasing the workspace and level of manipulation of the robot (Figure 36). Redesign the electromagnet lift interaction system from last year (see Section 7.1) also meant that we could ensure that the interaction medium was always in view of the camera. The puzzles created for the player to use the arm on were two magnet puzzles–one where an electromagnet would have to maneuver a magnetic ball out of a length of clear plastic tubing on the wall and one where the magnet needed to be held up to screws to remove a panel and the gripper would need to remove a cube from the space behind the panel–and a sliding puzzle–where the arm would have to push some sliding black out of the way in order to grab a regular hexagonal prism. The arm had to be on top level of the robot to been seen by the camera located on the middle level (see Section 7.2), and the robot also had to be able to fit through the door connecting two parts of the escape room together (see Section 7.4 for information about the rooms), which meant that the arm could not be too tall.

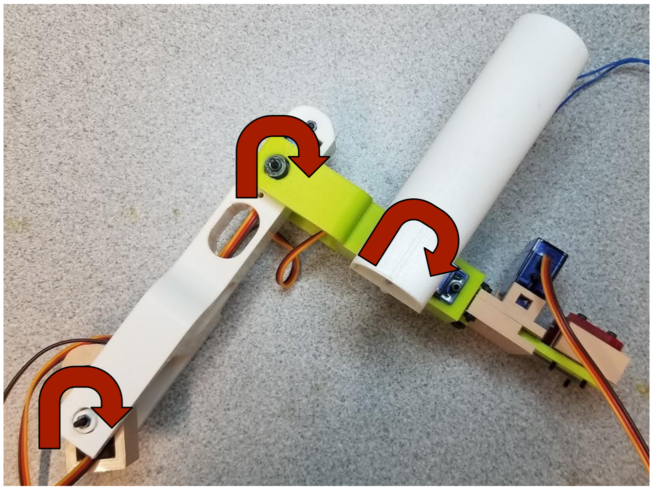


Figure 37: Arm Rotation

The arm was designed to have two degrees of freedom and is made up of five main components: three linkages, a gripper, and an electromagnet holder. The rotations of the arm, the magnet, and the gripper are actuated by servos as shown in Figure 37 (see Section 7.3.1 for information on the gripper and on magnet placement). The base linkage was designed with the robot's height constraint in mind.

While the base linkage was designed to be compact due to the height constraints, the second and third linkages were designed with visibility in mind. We wanted the arm to be visible the entire time it was being manipulated. This meant that the arm needed to reach the ground and still be visible. Experimentally, we found the range of visibility for the fisheye camera and determined that the gipper should be able to reach the ground 130 mm in front of the robot to be clearly seen. We calculated to minimize the length of the arm, the second link should be 155mm and the third link would be 673mm. However, 673mm is not large enough for the third link to have a servo and the gripper. We therefore resized so that the third link was a suitable length and rescaled the second link to match this new length.

The third link not only has the gripper on the end, but it also holds a servo to actuate the electromagnet. The placement of the electromagnet's servo is designed so that it can spin to hold the magnet out longer than the gripper's end in order to complete the magnet puzzles, while also being able to rotate out of the way for the rest of play time in order to not impede gripping ability. However, due to time constraints we were unable to power and test the arm.

7.3.3 Robot Wiring

The wiring of the robot was a critical component of its overall functionality. Without proper wiring, the robot would not be able to function as intended. The discussion about the robot's wiring will include the components involved and how they worked together to achieve the robot's desired actions.

The robot's wiring system was made up of several key components, including the Raspberry Pi (the Pi), sensors, actuators, and batteries. The wiring was responsible for connecting these components and enabling them to communicate with each other. Proper wiring was essential to ensure the robot moved and operated as intended. Since the robot was going to have two primary sensors- the camera, and the LEDs- and three main actuators- the servo for camera motions, motors for wheels, and the arm- the wiring system for the robot is presented in Figure 38, and each of these will be discussed separately.

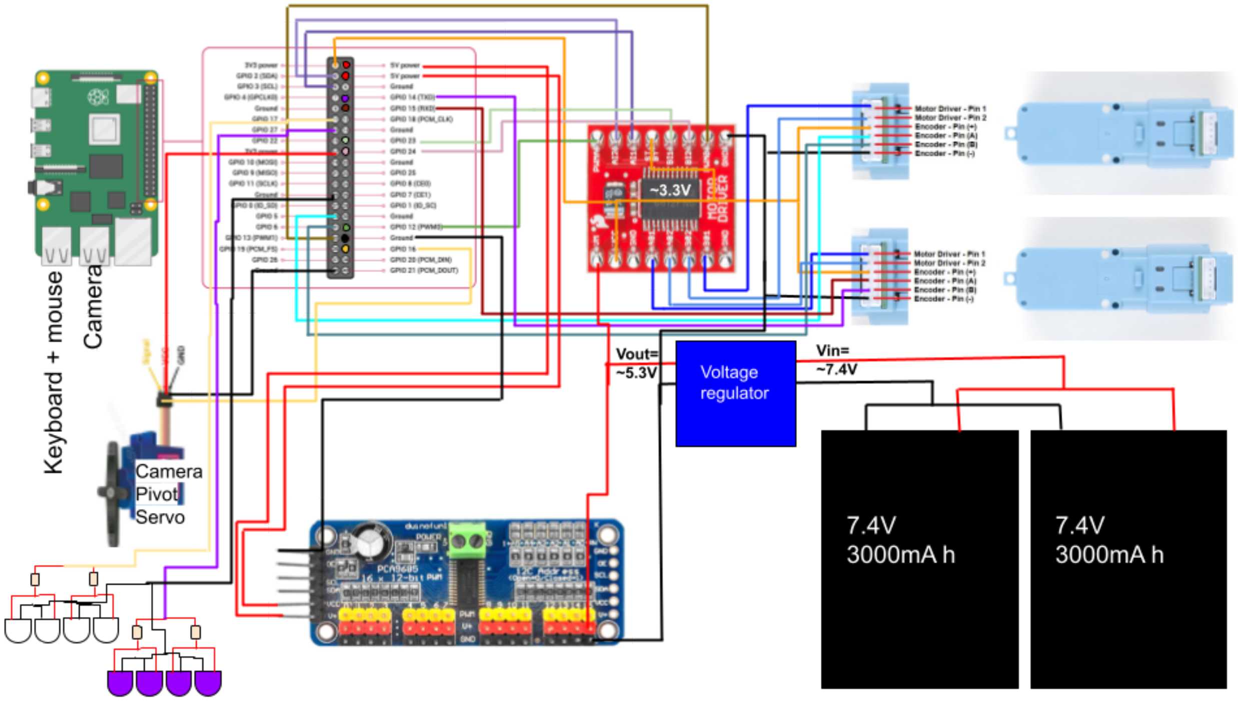


Figure 38: Robot Wiring Diagram

Sensors are components that detect physical or environmental changes and convert them into electrical signals that are transmitted through the wiring system. Connecting the camera to the Pi had been a relatively straightforward process. With the fisheye camera arriving with a USB cable, inserting it into the Pi resulted in a fully functional camera. Nonetheless, programming had been required to visualize the video feed and detect AruCo, as discussed in Section 7.3.4. Furthermore, two different sets of LEDs had been connected, including the regular light LEDs and the blacklight LEDs. By connecting the regular light LED, the robot was able to emit light, thus providing a better view in the dark, while the blacklight LED had enabled the robot to expose hidden messages that were written in UV-invisible inks. The LEDs were connected directly to the Pi on pin 11 (GPIO 17) and pin 13 (GPIO 27), respectively.

Actuators are components that receive electrical signals from the wiring system and convert them into physical motion. Implementing actuators was challenging as it required careful consideration of how the output pins were used and connected to the actuator. The wiring for the servo that controlled the camera motions was the easiest to implement. The SG90 Servo had only three wires: Vcc, GND, and Signal. To connect the servo to the pi, Vcc was connected to 3.3V of power on the Pi, GND was connected to the ground, and the signal was connected to an output pin, which in our case was pin 36 (GPIO 16).

To enable physical motion for the robot, a motor driver was used to connect the bridge between the two motors for the wheels and the Pi. The motor driver provided a power amplifier to amplify control signals and supply the necessary current and voltage the motor needed. The motor driver also provided a control circuit for speed control and motor direction control. A full wiring diagram for the motors is shown in Figure 39.

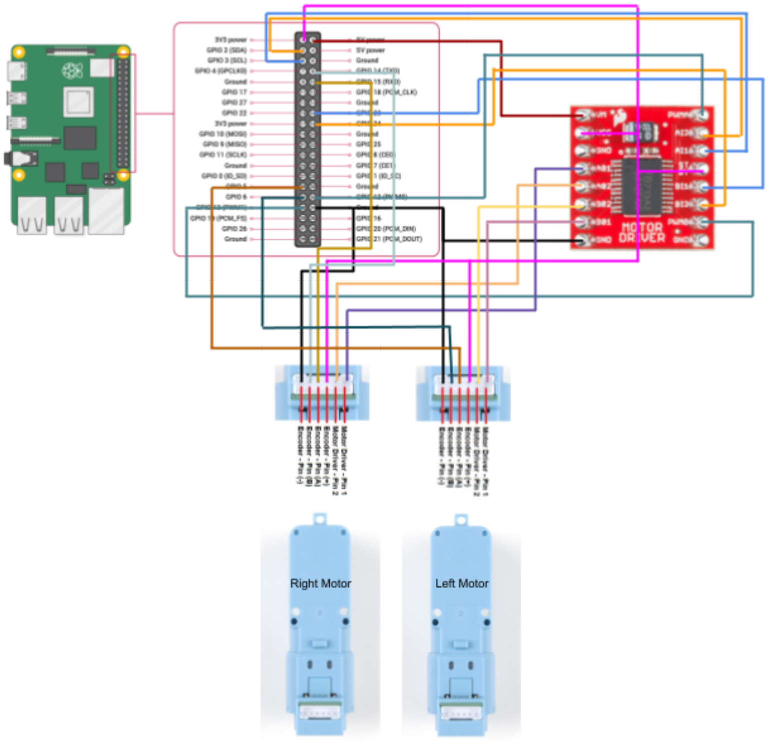


Figure 39: Wiring Diagram for Motors

7.3.4 Robot Implementation of Code

To control the robot, proper wiring and programming of the components were necessary. We opted for Python as the language of choice not only because last year's code was in Python, but also because it is the main language used by the Raspberry Pi Foundation. To enable robot functions, we imported several built-in libraries, including the keyboard module, the Eclipse Paho MQTT Protocol, and the OpenCV (cv2) library.

We used the keyboard module to create an interface for players to control the robot. This module provides functions for detecting and controlling keyboard events on the system. The module monitored keyboard events from the player by registering callbacks triggered when specific keyboard events occurred, and customized actions were performed in response to the keyboard events. See Appendix D for table of keyboard events used to control the robot.

The Eclipse Paho MQTT Protocol was the open-source implementation we used to connect the robot to the room and website. The MQTT had two main entities: publishers and subscribers. Publishers send messages labeled with topics to a broker, which is a message queue that receives and distributes messages to subscribers who have subscribed to the same topic. The broker ensures that each message is delivered to all subscribers that are interested in the topic (Figure 40).

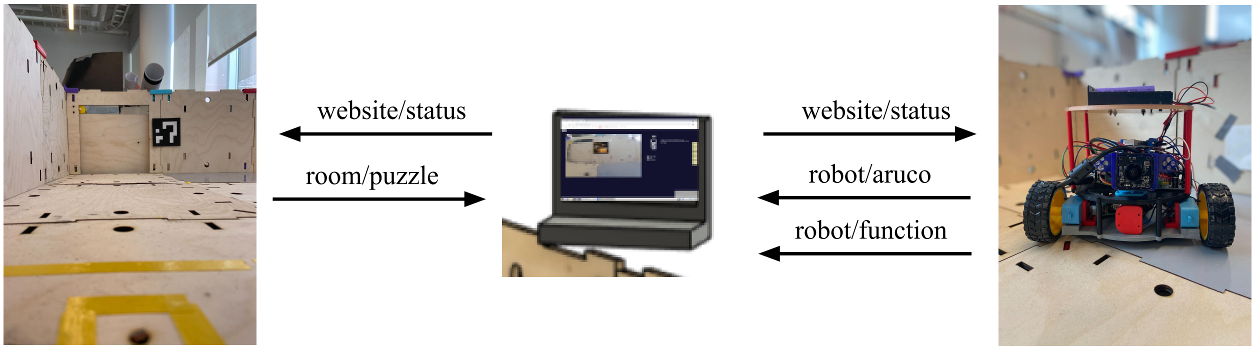


Figure 40: MQTT Diagram

Lastly, the OpenCV library is an open-source library that provides various functions and tools for image processing, manipulation, and analysis. OpenCV allowed us to perform video analysis and processing from the video feed returned by any type of camera, even non-programmable cameras. The most powerful tool that OpenCV brought us was the ability to identify ArUco markers, which are binary square fiducial markers. With ArUco, we were able to create puzzles, including scanning ArUco markers, position estimation of the robot, and camera calibration.

To explain more about ArUco, it is an open-source library for marker-based augmented reality applications. It provided a set of functions to detect and track square markers. ArUco markers are typically printed and can be detected and tracked by a camera or other imaging devices. The ArUco provided functions for generating and printing markers of different sizes and styles and detecting and tracking markers in real-time video streams. Each ArUco marker has its own unique ID, and the ID can be detected and returned. This allowed us to use ArUco in many different ways.

To gain a better understanding of how the code worked, we encourage readers to review the code implementation provided in Appendix A of this report. Additionally, we recommend checking out the accompanying README file for a detailed description of how to run the programs, including a step-by-step guide on how to execute the code.

7.4 The Escape Room

The room design included many discussions and collaborative meetings with all members of the team in order to ensure that integration of the room, robot and website would be possible. The basic requirements for the room were to be able to keep track of the robot inside the room, interact with the robot in a fun and intriguing way for the player, and reliably execute puzzle and story elements in the room. These requirements allowed for creative thinking on the robotics end to incorporate the needed sensing and interactive mechanisms to be seamlessly added to the room design. Many iterations and modifications were needed as part of the engineering process to achieve the expected result on the player's end.

7.4.1 Design

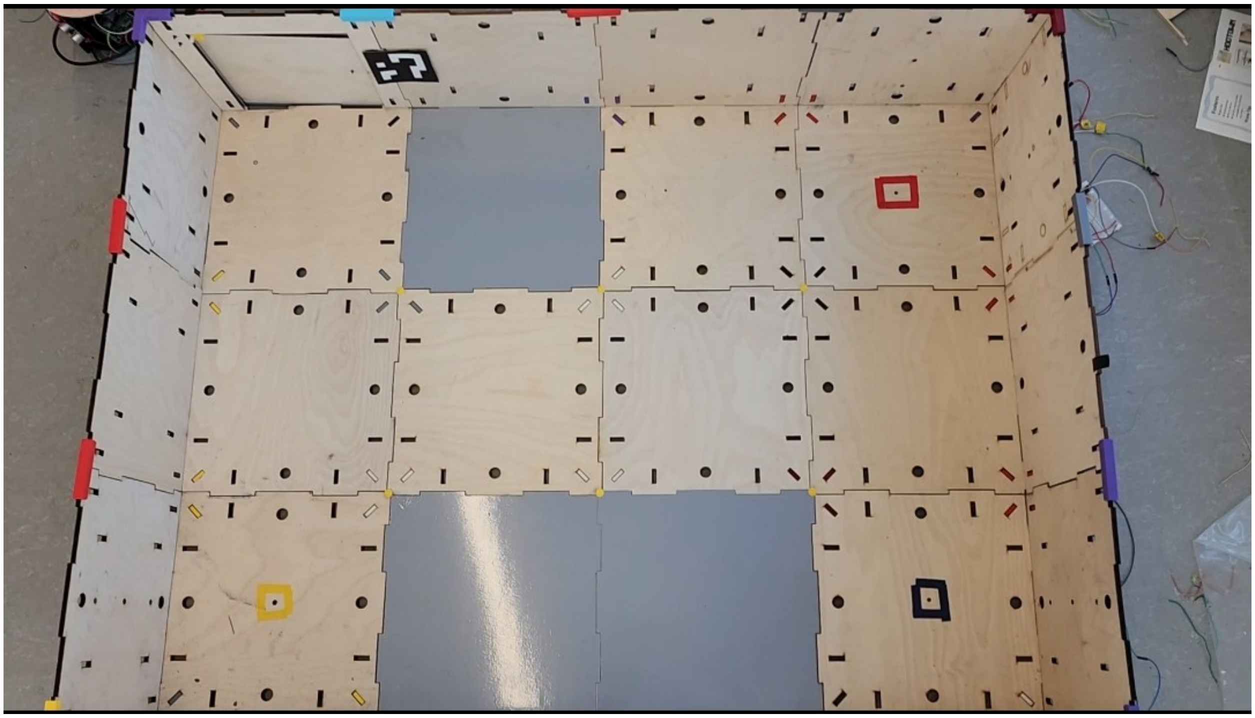


Figure 41: Entire First Room Birds Eye View

We started by assessing the basic layout of the wall and floor tiles from last year. We decided to go with two individual four-by-three-foot rooms that were connected with a door as seen in Figure 41. With longer walls we found it was easier to avoid becoming disoriented while navigating.

This allowed us to reuse the design of the floor and wall tiles developed by the team the previous year. This further allowed us to focus more on the puzzle aspect of the rooms while still maintaining the modularity of the space. We also decided to add roofs to both of the rooms to create a space that the players would feel more contained in and allow for the room to be more controlled in terms of lighting and visuals.

The next part of the room design was the physical puzzle interfaces that the robot would have to interact with. The puzzles that were embedded into the room design were the Simon Says puzzle, the hidden wall panel puzzle, and the ball stuck in the tube puzzle. These puzzles all required different uses of sensors, physical barriers and electronics to be fully realized.

The Simon Says puzzle was constructed by modifying the wall tiles to include inserts for LED lights at three different heights, this allows for different configurations of lights to be used based on camera height and the look wanted by the interactive media students. This also allows for the holes to be used in possible future designs without needing to be redesigned. For this puzzle two of the modified wall tiles were placed in three corners of the room with four LEDs in each corner. Red, blue and yellow LEDs were placed in the top and bottom inserts of the walls with each corner. These colors were chosen based not only on availability, but also to ensure that the flashing color shades would be different enough to be easily distinguished. To solve the puzzle one color of LEDs will flash at a time and they will continue to flash until the robot drives over a photoresistor hidden in the floor. This causes the current LEDs to stop flashing and a new set of LEDs to start flashing until all three sets are lit thereby completing the puzzle. For the embedded sensor this required modifying the floor tile to have a small opening in the middle to allow the photoresistor to detect when the robot drove over it as seen in Figure 42.

Figure 42: One corner of Simon puzzle

The hidden wall panel puzzle included modifying the previous team's design for a block dock to be smaller and the wall panel to be modified to fit the new wall holder. A lightweight panel was placed in front of the opening with some loose screws holding it in place as seen in Figure 43. This allowed the panel to stay in place but be easily removed when the player used the robot's magnet to remove the screws to reveal the cube hidden in the insert, as seen in Figure 44. This part of the larger signal tower puzzle did not require any sensors due to the fact that it would not have added anything important to the experience if this step was tracked by the room and website.

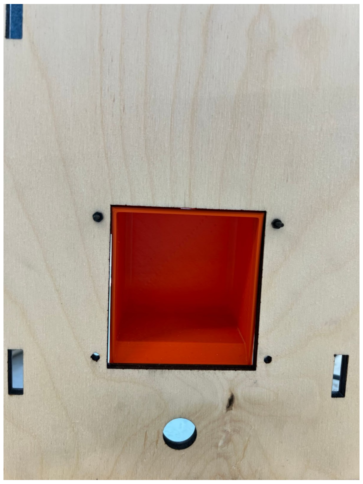


Figure 43: Wall without panel

Figure 44: Wall with panel

The ball stuck in the tube puzzle was a largely mechanical puzzle added to the second room. The puzzle consisted of clear tubing and pvc pipe connectors on one of the walls in the room. The puzzle is started when the website sends a message to the room at a certain point in the game to kick a small magnetic ball down the tube and into a small corner of the pipe. This mechanism consists of a small motor with a bar attached to it mounted to the outer wall, positioned in front of the motor is the small magnetic ball with the wall opening to the puzzle lined up with the ball position. Once triggered the motor kicks the ball into the opening and down the first hill. The player must utilize the magnet on the robot to drag the ball up to the top of the pipe and have it roll down a second hill into the room. The first challenge of this puzzle was to find materials that would be suitable for the design. We decided on small white pvc angle connectors and a clear tube for the hills and vertical sections. The wall panels were also modified to have more holes to fit a custom holder designed for the tube that would fit into the type of modular holes already present on the wall panels designed by the last team as seen in Figure 45. Holes were added to last year's design to allow the pipes to easily be put into the correct orientation for the hills. The pipes themselves had to be connected to allow the ball to roll as far as possible so that the only motion needed from the player was to raise the arm in a straight vertical line due to the design of the robot and player ease.

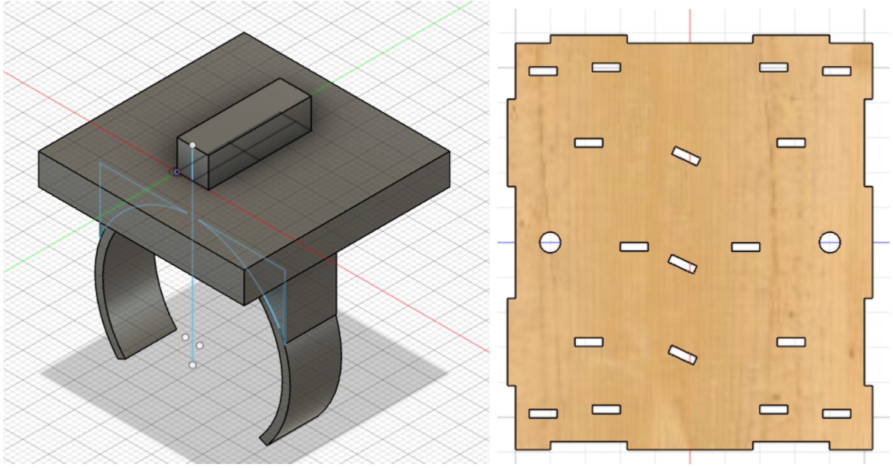


Figure 45: (Left) Model of tube holder, (Right) Model of modified wall

The last part of the room design needed was a working door between the two rooms. The pre-existing door panel was modified to allow a motor to be mounted to the top of the panel. We designed the door to be a sliding door utilizing a pulley system powered by a motor with an added caster-like piece to allow for easier sliding as seen in Figure 46. Once the website sends the message that the door needs to open the room triggers the motor to spin and reveal the second room to the player.

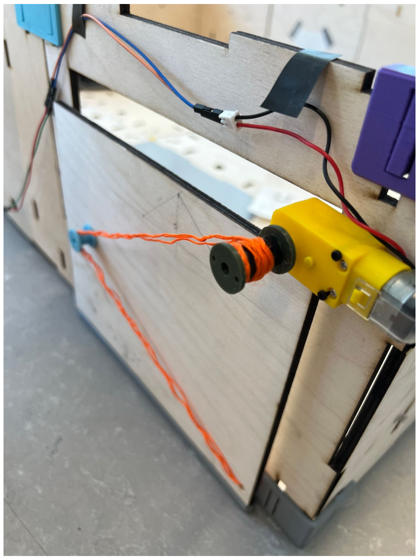


Figure 46: Door mechanism

7.4.2 Initial Designs

The room layout went through multiple iterations to get from the previous teams three by three cube to our four by three rectangle. How the room would interact and add to the players experience was also discussed in detail. In the early part of brainstorming for the room it was decided that moving aspects of the room were something we wanted to have in the final design. This evolved over the course of the year to become the sliding door separating the two rooms, the design went through multiple iterations before becoming a sliding door. Another design we considered was a hinged door that would open into the second room. This raised some concerns about removing the ability for the door to be potentially hiding some important puzzle aspect on the opposite wall, the robot being hit or running into the door while in the second room, as well as adding another obstacle to avoid in the second room. In order to alleviate these concerns we opted for a sliding door that sat between the two walls of the rooms.

The second moving aspect of the rooms was the mechanism for the tube puzzle which needed to only activate when triggered. Early designs for this puzzle included having the mechanism be in the first room but the puzzle be in the second room, this was not pursued further due to the distance between the two rooms and concern over the ball becoming stuck between the two rooms (Figure 47). Another solution that was not pursued past the brainstorm phase was potentially having a shelf in the room that would fall at the correct time in the game and reveal needed parts for a puzzle. In a standard computer environment this would be easily achieved, however the unknowns of where the items on the shelf would end up after falling and where the robot would be when the shelf fell introduced risk. This would make it more difficult to keep the robot safe and the experience the same for every player.

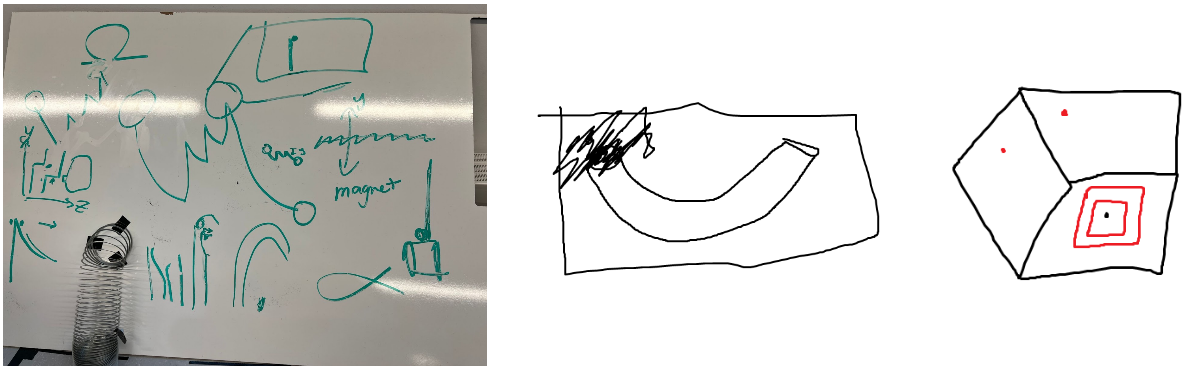


Figure 47: (Left and Center) Brainstorming for pipe puzzle. (Right) Brainstorming for Simon Says

7.4.3 Manufacturing

The room was predominantly manufactured by using laser cutting and 3D printing as seen in Figure 48. These processes were relatively cheap and fast, this allowed for multiple iterations to be tested easily and without wasting a lot of money. The walls and floors were made of ¼ inch wood panels. Wood was an easily accessible material and was inexpensive compared to the second most available option: acrylic panels. These panels were also very sturdy and could handle the amount of weight and force we were expecting to put on them from the puzzles and the robot.

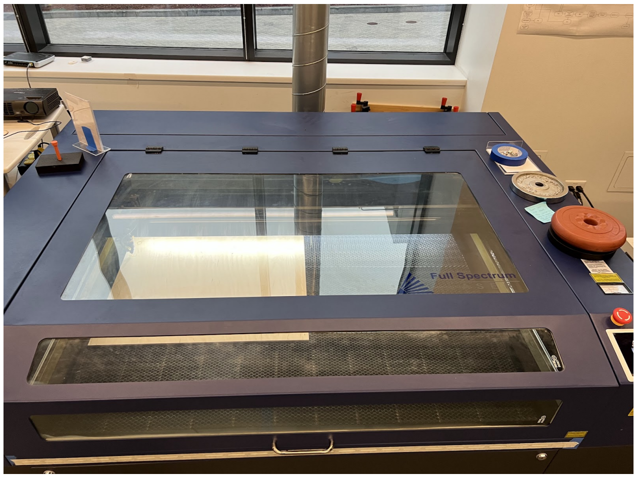


Figure 48: Laser cutting session

However, an issue with the wood panels that was only discovered after beginning the manufacturing process was that some of the panels were warped. This posed an issue for our floor because the robot was very easily stuck when panels were not even with each other. Instead of attempting to create a new floor with unwarped wood we decided to create a floor-clamping piece that screwed into an existing floor part to push the wood into the appropriate surface level (Figure 49). This piece was then added to every intersection of floor panels and created a smooth surface for the robot to drive on as seen in the figure below.

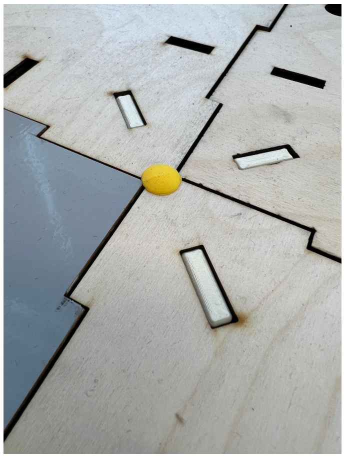


Figure 49: Floor clamp

Another issue that was not discovered until the manufacturing process was in tolerancing 3D prints to fit other physical parts. This issue happened with the pipe holders, the first print ended up being too close to the actual dimensions and due to the brittleness of the plastic it broke instantly. After adjusting the sizing a few times and printing more test pieces, eventually the pipe holder was able to securely keep the pipe in place (Figure 50). This issue was only able to be found after sending the part to be printed because of small differences in how the printer itself prints the plastic and the temperature at which the plastic melts and spreads.

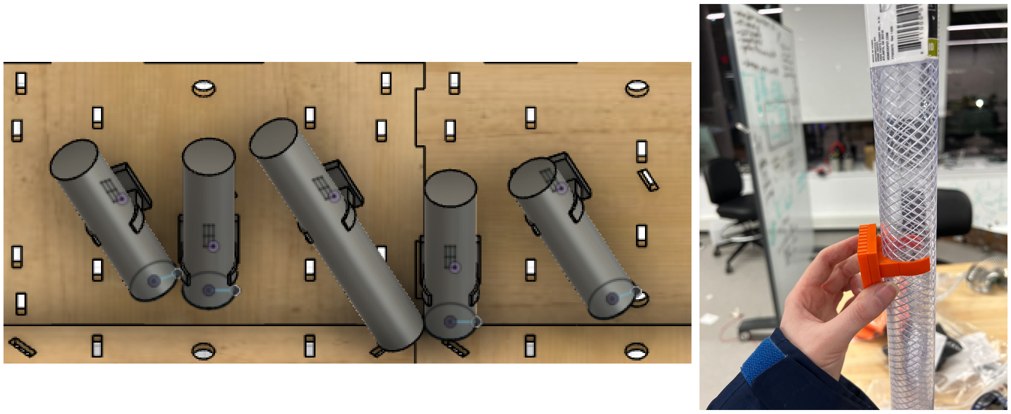


Figure 50: (Left) Pipe puzzle model. (Right) Custom pipe holder

7.4.4 Programming and Wiring

Certain puzzles required more programming and setup than others. The most complex puzzle in terms of electrical and software skills was the Simon Says puzzle. This puzzle relied on certain sensors and LEDs working together to create the correct experience for the player. The development process for this puzzle included a proof of concept circuit using a singular photoresistor and LED connected to the Heltec Wifi Kit 32 board. This board was chosen because the previous team used the same board and we decided to follow this decision in the hopes of being able to reuse and learn from their circuits and code. After the concept was proven possible, a full sequence of the puzzle was created in small scale on a breadboard. At this point, due to how the code was being set up we decided to have the LED they needed to go to be the only LED flashing; this altered the original plan for the puzzle slightly from having all corners flash and the player having to use a picture shown on the wall to figure out the order they needed to trigger the sensor. After a small scale version of the full puzzle was working as expected, the large scale version of the puzzle was wired and installed into the room with an individual breadboard reserved for each corner of the room and connected to the Heltec board in one of the corners (Figure 51).

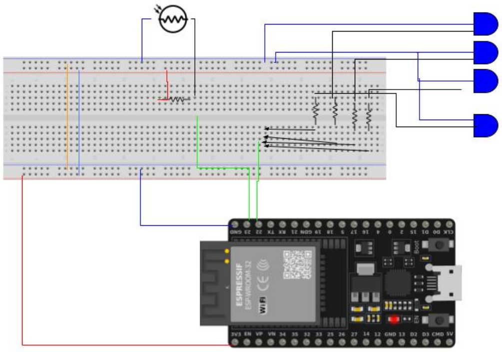


Figure 51: Circuit Diagram of Simon for 1 corner

The next part of the room programmed was the sliding door. The motor needed to spin exclusively when the game needed to open the door enough to let the robot into the second room. At first the motor was tested on a breadboard wired to a motor controller. After the code was tested and met the requirements, the motor was installed and wired to the door.

The last subsystem to be programmed was the motor for the pipe puzzle. A motor mount was designed and printed to hold the motor and ball in the correct orientation. The motor was tested with the controller and after meeting the requirements was wired and installed in the second room.

An issue that was found after the room was built and coded was that it was very difficult to connect the Heltec Wifi kit 32 board to the wireless network in order to connect the MQTT protocols together. In an interesting turn of events the Heltec board fried itself during testing which forced the room to be completely rewired and coded to instead use an Esspressif ESP32 Dev-Kit. This board was able to be connected to the wireless network and was the final piece in connecting the three systems together through MQTT.

We programmed the room using Arduino code files due to their compatibility with the board and having previous experience with Arduino programming. Each puzzle had its own method to keep everything organized. To keep the puzzles from running in the incorrect order, flags were created to only allow the puzzles to run in a certain order. This kept the code relatively linear and created an expected route for the player that the room could communicate to the website easily and the room would know when to be waiting for a message from the website to continue the in room puzzle progression. To see the arduino code created for this project please see the Appendix A.

8. Post Mortem

Throughout the span of this MQP, we faced plenty of challenges and obstacles that we had to overcome. Some of these we were expecting, while others we had not even considered as potential roadblocks until we got stuck at them. Many of these challenges were recurring and we struggled to deal with them throughout the year. The following are five of the many challenges that we overcame throughout the project: challenges of circular iteration, scheduling goals, navigating interdisciplinary teams, communication of scope, and a lack of producers.

8.1 Challenges of Circular Iteration

Circular iteration helped us fully flesh out many of our ideas and enhanced the project. However, it was not without its challenges. As a six person group spanning across three disciplines, we struggled with communication. We experienced difficulty in conveying progress and information effectively, especially when it became evident that deadlines would not be met. Ultimately, this became enough of a hindrance that we were not able to meet all of our original goals, and we had to scale down the project.

While circular iteration was useful in our project, we got caught in a loop of constantly going back and forth on our ideas, and wasted too much time being indecisive trying to cater to each other's needs and requests. What we needed to do was to have somebody on either the RBE or IMGD side make a decisive decision on what design constraints they were going to work with, and have the rest of the group work to make those constraints work. Instead, we all defaulted to what the other groups wanted, and spun our wheels for too long trying to decide what to do. If we had set clear expectations early for what our vision was, it would have ensured that no one part of the project would hold back any other part.

8.2 Scheduling Goals

An issue that we kept running into throughout this project was setting our own goals and meeting our personal deadlines. As a group it was difficult to meet deadlines because it seemed like every task had an unexpected set back. This caused us to become farther behind on the project than we originally planned for and caused us to have to work on the prototype into D-term, something we did not want to do. Some things we could have done differently to try to prevent this issue from happening are creating a more set schedule for our deadlines and keeping ourselves to those deadlines, another issue we had was figuring out our goals and keeping them within scope as we went further along in our process. Something we think could help would be constantly checking in with the team and seeing if adjusting our goals and reprioritizing aspects of the project would be helpful and reallocate resources and priorities to help subteams as they need it. We also think it would be helpful to set a schedule as soon as the project is realized to allow big deadlines to be met so that the year runs more smoothly overall.

8.3 Navigating Interdisciplinary Teams

As previously mentioned, our team was comprised of three majors: Interactive Media and Game Development (IMGD), Robotics Engineering (RBE), and Computer Science (CS). Navigating the interdisciplinary teams required a deep understanding of how each major worked in order to integrate them together successfully. Because the three majors often approached problems from different perspectives, effective communication and collaboration were crucial for the success of the project. For instance, some challenges arose due to conflicting terminologies, such as differences in the definition of the z-axis, with RBE considering it to traverse through a flat plane while IMGD interpreted it to lay flat. Furthermore, there were differing interpretations of "mapping" between RBE and CS, with RBE mapping referring to knowing the robot's position while CS mapping referred to creating a minimap on the website for the project. In addition, the team initially did not fully understand the breadth of knowledge and skills possessed by each discipline. For example, IMGD was not initially aware of the capabilities of the robot, including its design, implementation difficulty, and time required for the development. Despite these challenges, the team found that weekly advisor meetings were incredibly helpful in gaining an understanding of what the other teams were doing throughout the week. This fostered more effective communication and collaboration, ensuring that the project ran smoothly and that all team members were on the same page. Through active engagement in interdisciplinary communication and collaboration, the team successfully achieved their project outcome.

8.4 Communication of Scope

Scope became an issue for us as we headed further along into our project for a number of reasons, chief of which being communication. With such an interdisciplinary team, communication was always something we had to consider with intention. We knew that there would be a number of tasks that would fall completely outside of the scope of some team members and inside the scope of others, where other tasks would be sort of unclear as to who was best suited to tackle them. However, as we worked on our project, iterating circularly between our different teams, more and more of those undefined tasks started disappearing from our mental radar, only to reappear weeks later when it was either too late to address or a mad scramble to get done. Nobody wanted to let these small tasks slow us down, but over time as they built up, they started to affect our ability to reach larger goals, or to communicate larger issues. Our focus was torn between the work we thought we should be doing and the work we weren't sure was being done, and eventually those cracks started to become apparent. And again, nobody wanted to be the reason there were cracks, and nobody wanted their cracks to be the reason that the project couldn't continue, so we all persisted completing tasks and working towards our end goal. Even as our advisors nudged us towards scaling down or preparing for it as an eventuality, that hesitance to be the crack continued, and we didn't scale our project down even as missed deadlines started to chase us. It took us until our final deadlines were fast approaching to truly sit down and evaluate where our project stood, and to condense it down to an achievable size. Looking back, we think it would have been good to maintain some sort of task keeper, potentially one with a visual aid, to help make communication lines clearer in a large group, as well as do a better job of communicating our struggles to know when to scale down.

8.5 Lack of Producer Role

The nature of circular iteration means frequently stepping backwards from your project to reexamine how something was set up and how to better set it up to work with other features. While having a task list and communication during meetings is a wonderful start, when you have a large interdisciplinary team working on at least five things at once, it's no wonder when things start to fall through the cracks. Even as our team put effort towards making sure we all understood what things were being worked on, what needed to be worked on, and who was doing the work, we would still more often than not find little tasks that had simply been missed. Since we didn’t have a central person to keep track of how far along we were, we would also lose track of goals from time to time. To avoid this, we recommend having at least one assigned producer. This person would compile the work needed, the work being done, and the work already completed from each team, and then fill in the communication gaps to make sure everything gets done. IMGD projects often involve this role to maintain connection between artists and programmers for example, and given that this project has far more disciplines than your traditional video game, we hope future projects will include producers. There could also be more than one producer if necessary to compensate for the vast difference in specialties between IMGD and RBE, though if that were the case close communication would need to be kept between them about where progress stands. We also recommend that this producer keeps a visible task list available as they manage it, so that team members who need to have the ability to check which tasks need getting done, and who to talk to about tasks constraining their progress.

9. Recommendations for Future Years

When setting goals for ourselves at the beginning of this year we planned ambitiously. As such we were unable to accomplish all of our initial goals, and had to change the scope of the project as we progressed due to time constraints. The following are aspects of the project we were unable to create or fully flesh out. We recommend any subsequent teams work on completing these tasks.

9.1 Utilize Audio in the Experience

Audio is a significant part of the game experience, as it provides the player with environmental feedback and informs them of the general atmosphere of the game space they are within. It is deeply important for creating immersion as well, since real life experiences come with audio input, and without some sort of sound being played from the game, there is only so much realism that can be achieved. Unfortunately, audio is also one of the less glamorous parts of game design, and rarely gets the acclaim it deserves for the importance of its role. This was the regrettable case with our MQP, as the combination of time constraints and other priorities left us with little time to add in the audio cues that would boost our experience to the next level. Our recommendation for next year is to not overlook the importance of soundscaping, and to bring the experience to the next level by including things that we cut for time.

The simplest of these new additions would be to have audio queues for when tools are used, operations that happen in the room when the player interacts in a successful way, and when website buttons are pressed. These could be simple sound bites coming from the website, and they would greatly add to the player navigability of the space. During playtesting several testers commented how helpful audio cues would have been as well, indicating that this is a good first starting point. Additionally, the use of ambient sounds would boost the experience significantly, especially with the inclusion of a musical track to set the tone. Ambient music would also make other sounds less blaring, and could potentially open up the possibility of including proximity based sounds using sensors in the room without startling them with a sudden noise. Further, more ambient dialogue lines could be played to give environmental context without seeming out of place, which would further support the strong narrative throughout the room. We also recommend that a more human voice be given to the robot if it is kept as a companion. This might be in the form of recorded voice lines, or simply a better text to speech reader, but as it currently stands the robot cannot express nearly as much emotion as would be beneficial to the teammate role we want it to serve.

9.2 Add Mapping as a Tool

We started the project with the idea that we would add sensors to the robot in order to map where the robot is in the room. We started this process by swapping out the driving motors to be ones with encoders and placed–but did not wire in–an ultrasonic sensor facing a 45 degree angle on the rear of the robot. We however were unable to code these additional sensors due to time constraints. We recommend completing this process because having the robot map where it is will allow for a multitude of other opportunities such as being able to offer the players a mini map on the website.

Adding a minimap to the experience would be a good stretch goal for next year's group to add to the escape room. There are many merits to adding a minimap; firstly, it gives the players a clearer understanding of where they are in the room, as well as what they are able to work with in the room. This is especially true if you add elements of the room and puzzles into the minimap. Having a minimap is another step in making the player feel even more immersed in the game than they already are. Minimaps fit the vibe of a sci fi game very well, and would not feel out of place at all. Additionally, there are plenty of creative puzzle ideas that can only be done with the use of a minimap. For example, if you turn the lights off in the room or turn the camera off on the robot, you can force the player to rely on the minimap. You could also put secret codes or have things that are “invisible” in the room, show up on the minimap.

Beyond a mini map it also creates the possibility of having the robot “take control” at certain pivotal gameplay moments to ensure that certain planned “wow” moments happen as expected. For example we had planned on having the robot “laser cut” a panel off the wall in order to retrieve a game piece for a puzzle. We had planned on this happening by creating a sort of real life cut scene where the robot would take control, face the wall in a creative way and maneuver along an autonomous path in line with a section of the wall that would light up and act as if it were being laser cut. While this particular implementation idea was cut not only due to time, but also players being confused at the laser cutting concept, there are numerous other ways to realize this “taking control” concept.

Finally having the robot map would allow for safely imbuing more personality into the robot. In other versions of this game we played around with having the robot internationally list to the left due to an “uneven” environment (for instance if the setting was a boat rocking, the floor is still flat, but gravity pulls you to list left or right as it rocks). By knowing where the robot is you can safely have the robot avoid any props in the room you wouldn’t want it to hit. You can also have the robot say quirky voice lines at correct moments. For instance if you were to write a voice line about a painting, you can make sure that voice line will be delivered while the robot is looking at the painting in the room.

9.3 Incorporate More Theming into Experience

Theming was an essential aspect of game design that significantly enhanced player engagement. We recommended incorporating themes into various game elements to make the game more engaging for players. One approach was to make the website more "control panel-esque," which can add to the immersive experience and make players feel like they are controlling a futuristic system. Another way to incorporate themes is to decorate the interior of the room, giving it a space-themed look and feel. This can create a more immersive environment and enhance the player's experience as they navigate the robot around the room. Implementing these theming recommendations can make the game more engaging and create a more enjoyable experience for players.

9.4 Raspberry Pi Connection Improvement

For next year’s group, we recommend experimenting with different methods of connection between the different components of the project. One specific recommendation is to try using VNC to connect with the Raspberry Pi, instead of using Remote Desktop. The connection between the Pi and the desktop was often slow and laggy, and the IP address for the Pi was constantly changing. This required us to connect the Pi to a separate monitor to acquire the new IP address, so we could connect it to the Remote Desktop. We also recommend condensing all of the controls onto either a single keyboard, or onto a controller or control panel. The current setup utilizes both the keyboard of the computer that the website is running on, as well as a bluetooth keyboard. The former is used for typing any inputs on the website, such as the password, while the latter is used to control the robot and its various functions. This is a very confusing setup for playtesters, requiring us to explain which keyboards are used for which functions. It would be much simpler for any future groups to figure out how to combine the controls onto a single keyboard. Using a controller or control panel with joysticks and buttons also has its merits, as it can potentially make the experience feel more like a game.

9.5 Room Additions and Potential Improvements

For improvements on the room mechanically, we think that building off of the existing resources would be a good place to start for next year's team. For the room specifically it would be helpful to look into potentially creating wall and floor panels that can have embedded circuitry in them, this would fix this year's issue of having circuits outside of the room and the issue of disconnecting from taking place in the future. A first step would be to look into changing the current panels from wood to acrylic or another material that could handle close contact with electricity. Another improvement to the room could be to finish the mechanical build and coding of the second room that was designed and manufactured this year. By adding this second room into the escape room it would add another dimension of experience to the game. Another recommendation would be to think of creating mechanical props for the room itself; this could add to the overall theme of the room and also have a potential puzzle component. By making these actuate it can also add another layer of complexity to the room design itself and have a more immersive effect.

9.6 Furthering Arm and Gripper

We recommend testing and improving the arm and gripper. At the conclusion of this project we have done the construction of an arm with the constraints outlined in sections 7.2.1 and 7.2.2, however due to time limitations it remains untested. We recommend further iteration on the gripper to allow more flexibility in what shapes can be picked up. At present it is primarily designed to pick up a small cube and a small hexagonal prism, but we believe that by designing the gipper to be more flexible will free the game component to incorporate more game aspects that will further enhance playability, fun, and realism.

10. Conclusion

This project was a successful iteration on the concept of a robot escape room, taking it from a rough framework and making it into a playable experience. After having spent the beginning of the year repairing last year's escape room, we transitioned into implementing our own ideas. We chose to deconstruct last year's robot and start from scratch, adding a mechanical arm, as well as giving the robot more power. We brainstormed a new batch of puzzles for the players to solve. A storyline was crafted to give the room better theming and to give the player a sense of purpose, and we created a second room to add more depth to the experience. The website was redesigned to be more impactful and relevant in the user experience.

We held many brainstorming sessions, building out our ideas and concepts and constantly iterating on them to create the best experience we could. We ran playtesting sessions at every stage of development. Starting with Wizard of Oz playtesting, we used our phones connected to zoom calls to mimic the robot's camera to be able to test the initial room layout and puzzle designs, and as we progressed further into the project, we were able to add more elements into our playtests. Using the data we received from playtesting, we made adjustments to improve the user experience, refine our puzzles, and enhance the overall enjoyability of the player.

There are numerous avenues to explore for this project, and we hope the next iteration of the project will take into consideration our recommendations. A major change that would significantly enhance the playing experience would be the completion of the second room. There are plenty of tweaks to add as well, such as adding more audio to the game, theming the room and website better, and adding more props in the room, all with the goal of creating a more immersive escape room. Lastly, we recommend establishing strong communication between disciplines to ensure everybody is held accountable and is meeting deadlines.

This project was a successful next step in the creation of the new genre of robot escape rooms. We were able to use last year's work as a foundation to build off, and learn from their mistakes to continue progressing this project. We are hopeful for the future of this project, and we are excited to see where future groups decide to take this project.

Appendices

Appendix A: Github Links

https://github.com/EscapeRoomRobot/RobotEscapeRoom22-23

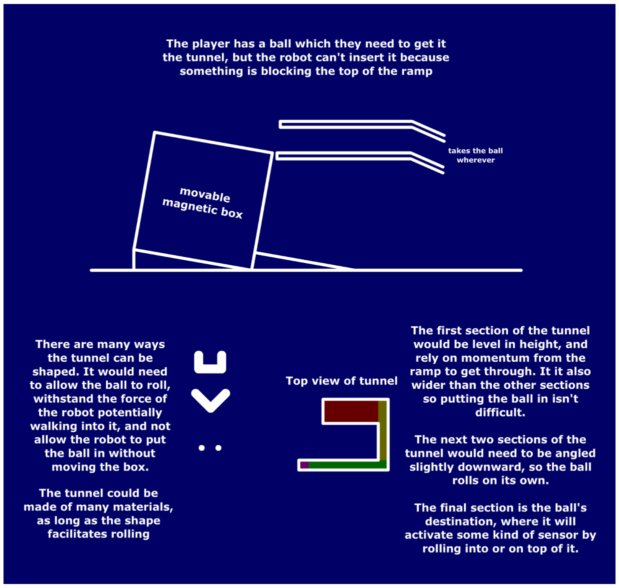
Appendix B: Playtesting Data

This is a timeline of what changes have been made in response to playtesting, starting with the beginning of C-Term

When the change happened	What the change was	Why the change happened
2/20	Decreased the size of the paper with the code "ROCKET"	it made it easier to see all the letters at once
2/21	We recontextualized the laser-cutting puzzle to be a task of removing screws	it was easier to understand
2/21	More powerful blacklight	it made it easier to see all the letters at once
2/27	Change the robot's starting rotation to face directly away from the red lights	it had been common for players to accidentally step on the red light sensor before they knew what was going on
2/27	Removed one axis of rotation for boxes in the box puzzle	the physical interaction between the robot and the boxes were too complicated and confusing
3/2	Removed the constraint that the two boxes must be pushed in a specific order	playtesters would often push one box, conclude it couldn't move, and not return to it
3/16	Replaced "frozen due to fear of the dark" with "robot stubbornly refuses to do anything until lights are on for OSHA reasons (use arm is disabled)"	playtesters had trouble seeing the second room from the door, due to low resolution and a limited ability to turn the camera
3/20	Added paper stars (with blacklight outlines) on the walls of the second room	we expect it will alleviate the common issue of playtesters never realizing they need to use the blacklight on the signal tower base
3/29	placed squares of tape in the corners of the first room	it needed to be more clear that there was something significant ON THE GROUND
3/30	added additional context to webpage wire untangling puzzle	players commented that they weren't sure why they were doing this puzzle/didn't recognize them as wires. They also consistently completed the puzzle in under 30 seconds

Appendix C: Scrapped Puzzles

Rube Goldberg Machine



Concept 1: In the corner of the room, there is a raised platform with a box sitting on top. There is a code on the wall behind the box

1. Due to the height, the box cannot be pushed, and must be moved using one of the arms.

Concept 2: There is a seesaw-like shelf on the wall with spherical objects on top.

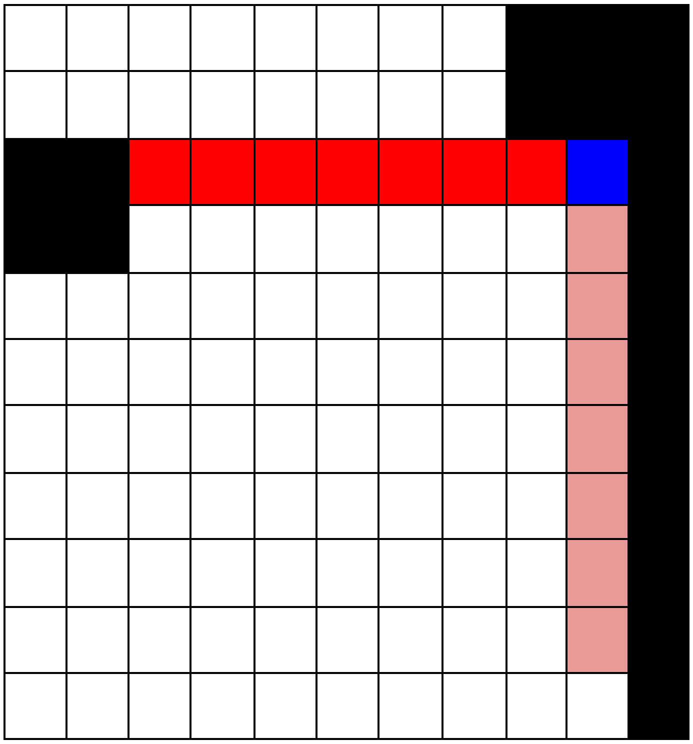
2. The shelf is pinned in place in the middle, and is initially tilted slightly to the right.
3. There is some sort of protrusion from the wall which prevents the seesaw from tilting further to the right.
4. The player must use a robot arm to lift the right side of the shelf, causing the objects to roll off so they can be used for the next task

A combination of these concepts with narrative → used to replace the power sources that were damaged during asteroid collisions with new ones from inside the crate

One-Way Door

1. The door would need to be made of a firm but light material. It can rotate 90 degrees, being either perpendicular or parallel (right up against) the wall.

2. The door is initially perpendicular to the wall. There is no resistance, so the robot can easily push the door open, but since the door can only rotate one way they must approach it from the correct side. Once the door is pushed against the wall the path would be open permanently.
3. This could be interesting if the environment is such that the door is first approached from the wrong direction, so the player can't open it.
4. The door would start in the dark red position, then be pushed into the light red position when approached from above. Black tiles are unmoving walls and the blue tile is the hinge which the door rotates around.



Detailed Input/Output Brainstorming

1. If we give the robot a fan, potential interactions include
    a. Blowing around debris
    b. Blowing papers away from scanners on the wall
    c. Blowing projectiles off of high shelves
2. If we implement pressure plates, potential interactions include
    a. Stepping on the plate
    b. Placing the box on a plate and going somewhere else
    c. Placing the box on one plate and standing on the other
3. In the corner of the room, there is a scanner on the floor which is covered by a piece of paper, taped to the ground only on the side closest to the wall.
    a. There is a barrier blocking the paper. It can be moved by stepping on a pressure plate, but as soon as they step off the barrier comes back.

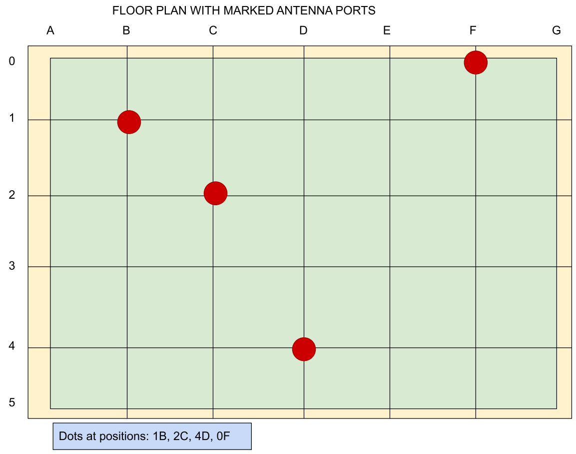
   b. The solution is to stay on the plate, use the fan to flip the paper, then scan the code from a distance.

4. There is a passageway wide enough for the robot. The bottom half is a wall, the top half is a piece of paper.
   a. The paper is being held up by tape in the following locations
      i. Top of the left side
      ii. Bottom of the left side
      iii. Left side of the top
   b. Use the fan to push away the right side of the paper, revealing an April tag on the wall behind it.

Map-Based Puzzle

Player will:

1. See *physical map* on room wall & robot location *virtual map* in webpage corner
2. Use webpage (or another puzzle input) to find the parts of a coordinate
   a. Potentially bolded letter and number on the webpage that sits there the whole time. [e.g. sign**a1** tower]
3. Look on virtual map to see several coordinates are given, then find the position that matches webpage coordinates, move to that spot → potentially w/ antenna → grippy arm



Dots at positions: 1B, 2C, 4D, 0F

   a. If the task is simply to move to that location, we absolutely need sounds and visual markers on the website to indicate that something has been accomplished.
   b. Is there an in-universe reason that something important is happening as a result of just standing in an unmarked place? It's not critical, but I think we should avoid a situation where the player goes from trying something random directly into the puzzle being solved.

Appendix D: Keyboard Events to Control Robot

Key	**Robot Action**
Up Arrow	Moves the robot forward.
Down Arrow	Moves the robot backward.
Right Arrow	Turns the robot right.
Left Arrow	Turns the robot left.
W	Move the camera up.
S	Move the camera down.
Q	Enables scanning for AruCo.
L	Turns the lights on.
B	Turns the blacklights on.

Bibliography

Alex. “What Did The World’s First Escape Rooms Look Like?” *Exciting Escapes* (blog), November 3, 2021. https://excitingescapes.co.uk/blog/what-did-the-worlds-first-escape-rooms-look-like/.

Ascalon, Anecia. “The History of Escape Rooms (2021) | Blog | The Escape Game,” March 31, 2021. https://theescapegame.com/blog/the-history-of-escape-rooms/, https://theescapegame.com/blog/the-history-of-escape-rooms/.

Bakhsheshi, Farkhondeh Fazel. “Escape Rooms: A New Phenomenon in Tourism.” In *2019 International Serious Games Symposium (ISGS)*, 38–41, 2019. https://doi.org/10.1109/ISGS49501.2019.9047040.

Buckingham, Owen, Edward Matava, Alyssa Moore, and Matthew Nagy. “Robot Escape Room,” April 27, 2022. https://digital.wpi.edu/pdfviewer/b2774000v.

Cerebral Palsy Foundation. “Xbox Adaptive Controller,” May 18, 2018. https://www.yourcpf.org/cpproduct/xbox-adaptive-controller/.

Coanda, Iulia, and Stef Aupers. “Post-Human Encounters: Humanising the Technological Other in Videogames.” *New Media & Society* 23, no. 5 (May 1, 2021): 1236–56. https://doi.org/10.1177/1461444820912388.

Csikszentmihalyi, Mihaly. “Flow: The Psychology of Optimal Experience,” 1990.

"Crimson Room on CrazyGames." Accessed October 12, 2022. https://www.crazygames.com/game/crimson-room.

Eladhari, Mirjam P, Anne Sullivan, Gillian Smith, and Josh McCoy. "AI-Based Game Design: Enabling New Playable Experiences," n.d.

EscapeHour. "Main 5 Types of Escape Rooms You Will Play," 2018. https://escapehour.ca/blog/45-main-5-types-of-escape-rooms-you-will-play/.

Eukel, Heidi, and Briyana Morrell. "Ensuring Educational Escape-Room Success: The Process of Designing, Piloting, Evaluating, Redesigning, and Re-Evaluating Educational Escape Rooms." *Simulation & Gaming* 52, no. 1 (February 1, 2021): 18–23. https://doi.org/10.1177/1046878120953453.

Fernández-Vara, Clara, and Ira Fay. "Well Played (Vol. 10, No. 1)." *ETC Press* (blog), April 6, 2021. https://press.etc.cmu.edu/index.php/product/well-played-vol-10-no-1/.

Fogg, BJ, and Clifford Nass. "How Users Reciprocate to Computers: An Experiment That Demonstrates Behavior Change," n.d., 2.

Fotaris, Panagiotis, and Andrew Blake. *ECEL 2022 21st European Conference on E-Learning*. Academic Conferences and publishing limited, 2022.

Gao, Yuan, Elena Sibirtseva, Ginevra Castellano, and Danica Kragic. "Fast Adaptation with Meta-Reinforcement Learning for Trust Modelling in Human-Robot Interaction." In *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 305–12, 2019. https://doi.org/10.1109/IROS40897.2019.8967924.

Gómez-Urquiza, Jose L., Juan Gómez-Salgado, Luis Albendín-García, María Correa-Rodríguez, Emilio González-Jiménez, and Guillermo A. Cañadas-De la Fuente. "The Impact on Nursing Students' Opinions and Motivation of Using a 'Nursing Escape Room' as a Teaching Game: A Descriptive Study." *Nurse Education Today* 72 (January 1, 2019): 73–76. https://doi.org/10.1016/j.nedt.2018.10.018.

Grammenos, Dimitris, Anthony Savidis, Yannis Georgalis, and Constantine Stephanidis. "Access Invaders: Developing a Universally Accessible Action Game." In *Computers Helping People with Special Needs*, edited by Klaus Miesenberger, Joachim Klaus, Wolfgang L. Zagler, and Arthur I. Karshmer, 388–95. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer, 2006. https://doi.org/10.1007/11788713_58.

Harwood, Fiona. "Wizard of Oz Testing – a Method of Testing a System That Does Not yet Exist.," August 30, 2018. https://www.simpleusability.com/inspiration/2018/08/wizard-of-oz-testing-a-method-of-testing-a-system-that-does-not-yet-exist/.

Heikkinen, Outi, and Julia Shumeyko. "Designing an Escape Room with the Experience Pyramid Model." Fi=AMK-opinnäytetyö|sv=YH-examensarbete|en=Bachelor's thesis|. Haaga-Helia ammattikorkeakoulu, 2016. http://www.theseus.fi/handle/10024/112798.

"Introduction | Human-Robot Interaction." Accessed October 9, 2022. https://humanrobotinteraction.org/1-introduction/.

Lin, Charlotte. "Escape Room AI." *The Chatbot* (blog), March 31, 2022. https://thechatbot.net/escape-room-ai/.

López-Pernas, Sonsoles, Aldo Gordillo, and Enrique Barra. "Technology-Enhanced Educational Escape Rooms: A Road Map." *IT Professional* 23, no. 2 (March 2021): 26–32. https://doi.org/10.1109/MITP.2021.3062749.

Luttrell, Aviva. "What Science Fiction Can Teach Us about Survival." *Clark Now | Clark University* (blog), July 10, 2020. https://clarknow.clarku.edu/2020/07/10/what-science-fiction-can-teach-us-about-survival/.

McCoy, Joshua Kristian. "The Used Future Aesthetic Explained." Game Rant, June 22, 2022. https://gamerant.com/science-fiction-used-future-aesthetic-explained/.

Nass, Clifford, and Youngme Moon. "Machines and Mindlessness: Social Responses to Computers." *Journal of Social Issues* 56, no. 1 (2000): 81–103. https://doi.org/10.1111/0022-4537.00153.

Pan, Rui, Henry Lo, and Carman Neustaedter. "Collaboration, Awareness, and Communication in Real-Life Escape Rooms." In *Proceedings of the 2017 Conference on Designing Interactive Systems*, 1353–64. DIS '17. New York, NY, USA: Association for Computing Machinery, 2017. https://doi.org/10.1145/3064663.3064767.

Perkins School for the Blind. "An Overview of Braille Devices." Accessed April 16, 2023. https://www.perkins.org/resource/overview-braille-devices/.

Pinney, Joel, Fiona Carroll, and Paul Newbury. "Human-Robot Interaction: The Impact of Robotic Aesthetics on Anticipated Human Trust." *PeerJ Computer Science* 8 (January 14, 2022): e837. https://doi.org/10.7717/peerj-cs.837.

Pruessner, Jens C., Frances Champagne, Michael J. Meaney, and Alain Dagher. “Dopamine Release in Response to a Psychological Stress in Humans and Its Relationship to Early Life Maternal Care: A Positron Emission Tomography Study Using [11C]Raclopride.” *The Journal of Neuroscience* 24, no. 11 (March 17, 2004): 2825–31. https://doi.org/10.1523/JNEUROSCI.3422-03.2004.

Sandoval, Eduardo Benítez, Jürgen Brandstatter, Utku Yalcin, and Christoph Bartneck. “Robot Likeability and Reciprocity in Human Robot Interaction: Using Ultimatum Game to Determinate Reciprocal Likeable Robot Strategies.” *International Journal of Social Robotics* 13, no. 4 (July 1, 2021): 851–62. https://doi.org/10.1007/s12369-020-00658-5.

SCRAP. “SCRAP.” Accessed October 24, 2022. https://www.scrapmagazine.com.

Shahid, Suleman, Emiel Krahmer, and Marc Swerts. “Child–Robot Interaction across Cultures: How Does Playing a Game with a Social Robot Compare to Playing a Game Alone or with a Friend?” *Computers in Human Behavior* 40 (November 1, 2014): 86–100. https://doi.org/10.1016/j.chb.2014.07.043.

Sheridan, Thomas. “Human-Robot Interaction: Status and Challenges.” *Human Factors* 58 (April 20, 2016). https://doi.org/10.1177/0018720816644364.

Singh, Kiran Jot, Divneet Singh Kapoor, and Balwinder Singh Sohi. “Chapter 11 - All about Human-Robot Interaction.” In *Cognitive Computing for Human-Robot Interaction*, edited by Mamta Mittal, Rajiv Ratn Shah, and Sudipta Roy, 199–229. Cognitive Data Science in Sustainable Computing. Academic Press, 2021. https://doi.org/10.1016/B978-0-323-85769-7.00010-0.

Sofaer, Joanna, and Magdolna Vicze. “Creative Practice and the Limits of Evidence in Journey to the Beginnings.” *Journal of Museum Education* 45, no. 3 (July 2, 2020): 350–56. https://doi.org/10.1080/10598650.2020.1768788.

Stasiak, Andrzej. “Escape Rooms: A New Offer in the Recreation Sector in Poland.” *Tourism / Turyzm* 26, no. 1 (June 30, 2016): 31–47. https://doi.org/https://doi.org/10.1515/tour-2016-0003.

Stuart, Keith. “What Do We Mean When We Call a Game ‘Immersive’?” *The Guardian*, August 11, 2010, sec. Technology. https://www.theguardian.com/technology/gamesblog/2010/aug/10/games-science-of-immersion.

Tarssanen, S, and M Kylänen. *A Theoretical Model for Producing Experiences – A Touristic Perspective.* Vol. Lapland Centre of Expertise for the Experience Industry. Articles on Experiences 2. Lapland University Press, 2005.

Veldkamp, Alice, Liesbeth van de Grint, Marie-Christine P. J. Knippels, and Wouter R. van Joolingen. “Escape Education: A Systematic Review on Escape Rooms in Education.” *Educational Research Review* 31 (November 1, 2020): 100364. https://doi.org/10.1016/j.edurev.2020.100364.

Wiemker, Markus, Errol Elumir, and Adam Clare. “Escape Room Games: ‘Can You Transform an Unpleasant Situation into a Pleasant One?,’” November 2015.