Cost-Effective Iterative Design of Large-Scale Escape Room Puzzles

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Abstract*— The "reverse-play slot machine" is the functional piece corresponding to the "menu puzzle" and is the product of numerous design changes and prototype iterations. Functional and representative prototypes were created based on drawings, SolidWorks models, and research on four-digit combination locks. Materials were carefully selected and tested to reduce cost and build time while maintaining the quality of working mechanisms as well as aesthetics. The target market, undergraduate students at Northeastern, was considered and tailored to in every iteration of the design process. The team defined success with this target market as being three-part: The manufactured object needed to visually impress the players, the solution had to be easy to solve, and the mechanism needed to be both easily understood and satisfyingly tactile. The first prototype of the team's components didn't include the slot machine. This was to reduce cost and focus testing on the puzzle. Based on the feedback from this preliminary round of testing, the team decided to move forward with a menu puzzle and began working on the slot machine. Guided the goal to use low cost materials, tests were conducted quickly and often to redesign components of the object until their quality aligned with what the team had defined for success, finally reaching the object presented at the Escape Room showing. Although quantitative testing was performed in class, it was mainly the qualitative testing which informed design decisions. The final slot machine houses the solution mechanism for the menu puzzle, a clue for the next puzzle, a trap door, and a safe. This paper also briefly covers the impact of other team's puzzles on design decisions of the slot machine. The in-class testing revealed faults in the lack of engagement, which were addressed in the final prototype. Cost analysis of materials was the most significant factor in the design process, aiming to maximize the quality of user experience without sacrificing the budget.

Keywords—Escape Room, Reverse Slot Machine, Prototype Iteration, Tactile Input, Component Testing, Qualitative and Quantitative Testing, Functional Mechanism, User Experience, Dials, Manufactured Object.

I. Introduction

An escape room often tries to capture the emotion of a movie or book through physical puzzles and games in a single, enclosed room. Just like a good movie, the plot (or pathway) of events isn't clear until the very end. To be successful, these rooms have to strike a good balance between clarity and surprise, all while engaging players through intellectual challenge and tactile satisfaction.

As a course section, the group was familiar with escape rooms through last semesters project, an escape room board game. The lessons learned from the rapid prototyping done during this semester was fundamental to our approach in building an entire escape room. The first meeting was used to determine a theme around which all puzzles should focus, in order to create the most cohesive experience for the end users. The 23-person class was then divided into smaller four-person teams which would individually focus on creating separate puzzles, and 4 large committees responsible for different aspects of the room's operation. This paper will focus mainly on the work done in the four-person team, in producing a working *reverse slot machine*.

The four-person team referred to was Rickard Stureborg, Justin Sargunas, Nathan Schneider, and Ramez Mubarak. This team realized early on the challenge of maximizing the positive impact to the escape room while minimizing cost. Cost was identified as a realistic limitation for many of the goals wished to achieve, as discussed in section II. For this purpose, iterative design was preferred to rapid prototyping, with cost analysis being a significant method of determining feasibility for each design and thereby informing many of the design changes made. This paper focuses on each designs faults and improvements made to the next iteration focusing mainly on the impact decisions had on the cost of the project.

II. Problem Analysis and Defining 'Success'

This section will address the factors considered in defining an 'impressive' manufactured object, 'good' user experience, and 'success' of the project.

A. Good User Experience

The immediate reaction of players of the escape room is important for setting the emotion and attitude of these players towards the room. A room which immerses the players immediately is more likely to engage them fully and is thereby more likely to provide a better user experience. To achieve this, the team decided to try creating a project that is immediately impressive without knowing how it works. The team had submitted a proposal for a slot machine and decided that if this project were to immediately impress players it needed to be both realistic and stand out in the room. It was therefore decided that the machine needed to be *large* and *colorful*. Additionally, the large object would provide a satisfying tactile response when solving the puzzle, the general idea being that the object would dispense the next clue after the slot machine's wheels had been turned to the correct combination.

B. Defining Parameters of Success

The other framing definition the team had to make early in the process was to establish a yard-stick for 'success.' Not only did this create a frame for evaluating the success of final product but it helped guide design decisions and objectives of testing. Every design iteration was influenced by this yard-stick as the changes aimed to come closer to meeting the requirements of success. Through meetings with the team, four main criteria were established as a 'successful' project

1) The interactive components of the machine should be obvious and function intuitively. This means users should not try pulling on or looking for components that don't lead to the solution, but it also means they should almost immediately understand which components need to be manipulated (dials and lever) to reach the solution.

2) The action of pulling the lever should immediately result in auditory response from the next clue being dispensed, as an indication that the puzzle has been solved. Thereby, there should be no question of whether the puzzle has been solved or not.

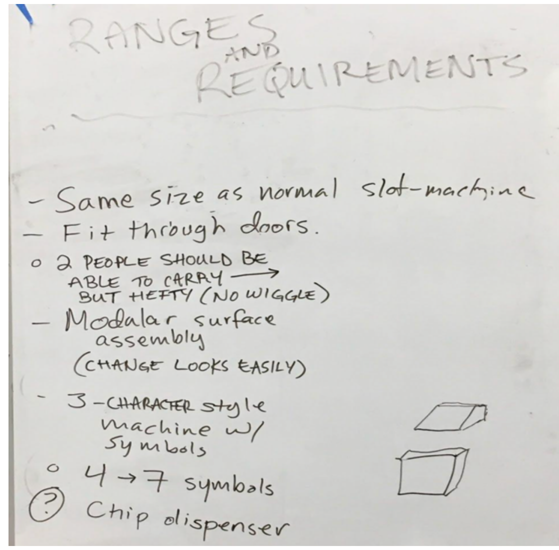
3) The machine should be able to function despite misuse. For example, pulling the lever quickly, shaking the machine, or slamming the dials should not break the mechanism by which the machine works, nor should it dispense the next clue.

4) The slot machine should be a memorable piece to the escape room and should be identified as one of the player's favorite.

The extent to which these parameters were met will be further discussed in subsection VI.

Further, some ranges and requirements were written down for the slot machine to aid the design process. See Figure 1.1.

Figure 1.1



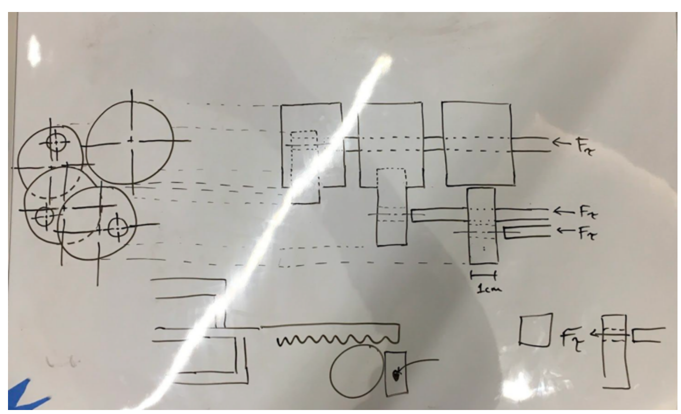
III. Iterative Design Evaluation

After the goals and general function of the slot machine had been defined, the team set out to create a design from which the fabricated object could be built. In contrast to the project of GE1501[1], rapid prototyping would be too expensive to be feasible for a project of the size the team envisioned.

A. Iteration 1 of Dial-Peg Mechanism

The very first meeting was used to determine the mechanism by which a puzzle could be engineered into what should accurately represent a slot machine. Whiteboarding, the first design was roughly drawn as shown below:

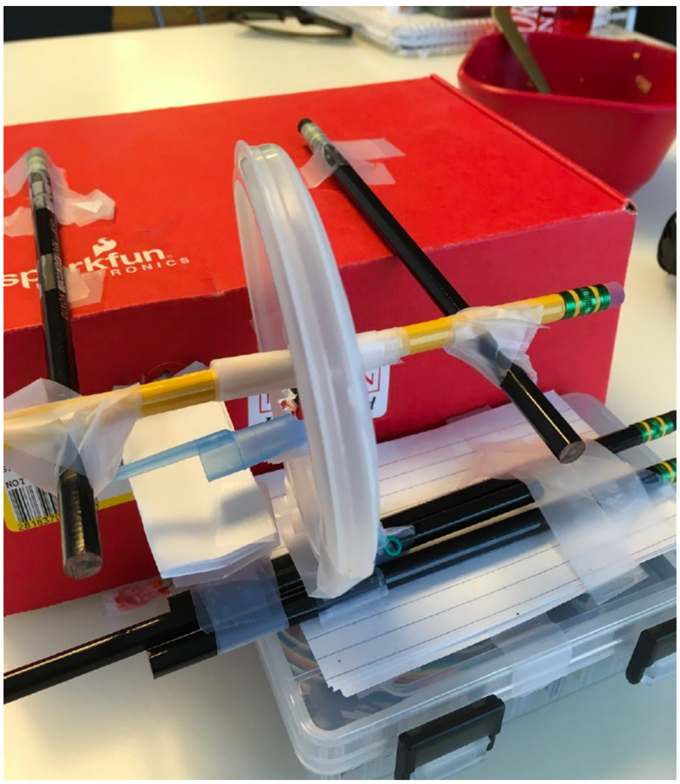
Figure 2.1



The design featured three dials, just as in the final design, on which symbols would be printed to represent a slot machine. When these dials were turned, interlocking gears (see the three offset circles with holes) would rotate to align with a moving three-pronged peg (bottom). If the gears were turned to an incorrect combination, the pegs would get stopped by the hard surface of the gears and thus the desired action of releasing an object would not occur. If they were aligned correctly, the peg ends would enter the holes of the gears and this movement of the pegs would release the desired object. The exact mechanism by which the clue would be dispensed was not yet decided on and is discussed in subsection [ENTER THE SECTION]. The peg system would move based on the rotational movement of the slot machine's lever using a gear and ratchet system (bottom).

A small prototype was cut out of cardboard to assess the feasibility of gears as the driving mechanism. Results identified the need for laser cutting in regard to manufacturing the gears. Another prototype was created for the interaction of a singular gear and a singular peg. This second prototype can be seen below.

Figure 2.2



B. Iteration 2 of Dial-Peg Mechanism

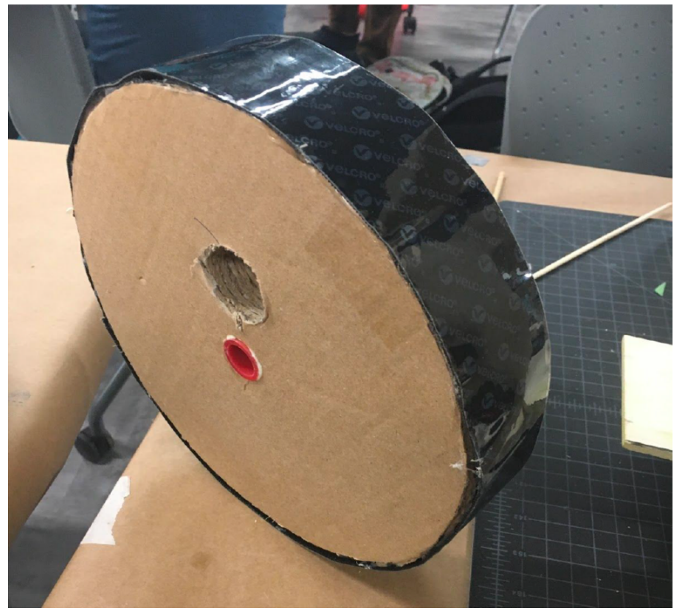
In analyzing the first design iteration, the cost could be broken down into a few components. The following table describes the cost analysis of the first design:

Table 2.3: Cost of Components

Component	**Estimated Cost (USD)**	**Notes**
Dials	20.00	*Hardwood*
Pegs	3.00	*Wooden Dowels*
Ratchet	5.00	*Wooden, multiple layers, laser cut*
Gears	20.00	*Wooden, multiple layers, laser cut*

This first design would bring the budget immediately to 48 dollars, for the mechanism only. It was therefore decided to simplify the design to reduce required parts. The second design was drawn up on paper, featuring dials which housed the holes for the peg system deep on the wheel. Thus, the dial could still stick out of the machine without showing this hole to the user, but only three dials were required rather than the 6 interlocking gears in the previous design. This design decision made it to the final version of the slot machine and is shown below:

Figure 2.4



Further, the peg structure was simplified to three separate arms on a track. This design would allow the lever-ratchet system to function by pulling the track rather than pushing, which was determined to be a more reliable and flexible design. A prototype of this Dial-Peg mechanism was built and presented to our peers. It was built entirely out of scrap cardboard to reduce cost. The only purchased part of this prototype was the dowel, which was later used for a team members separate project, and therefore not in the budget.

Figure 2.5

C. Formal Design Submission

After several iterations of improving the design, it was decided necessary to produce a digital design from which dimensions and general shapes could be decided. The team used SolidWorks to create this design and focused on the outside frame as this would determine the dimensions of the slot machine. The SolidWorks modelling was a cost-reduction method in that it replaced prototyping for the size and shape of the machine. Below is the final SolidWorks model and its derived dimensions.

Figure 2.6

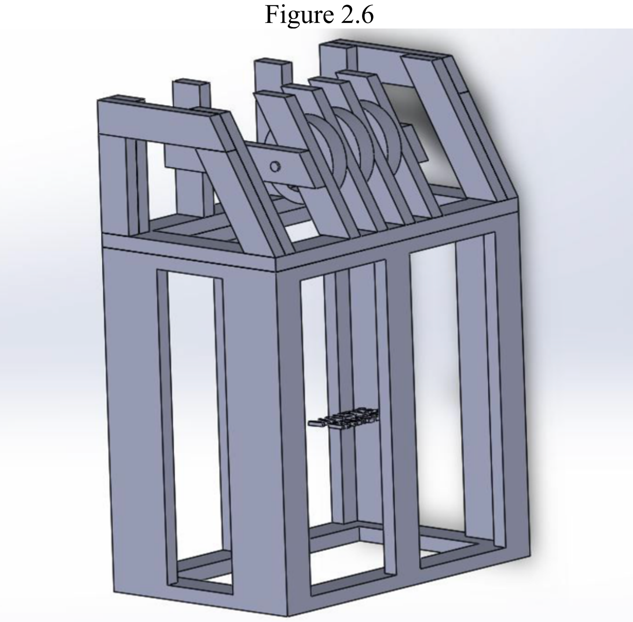
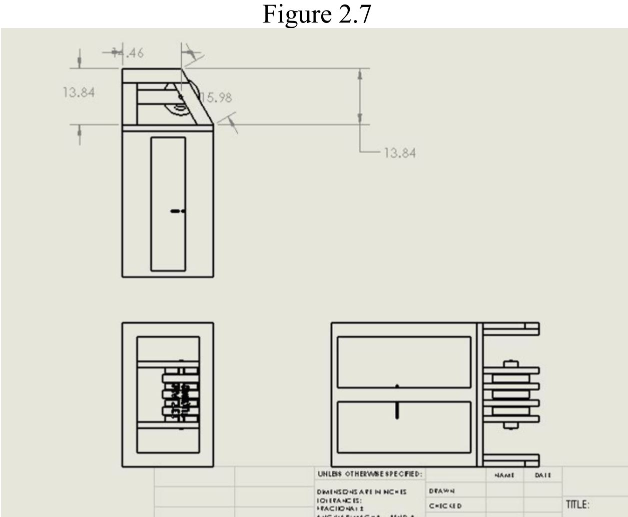


Figure 2.7



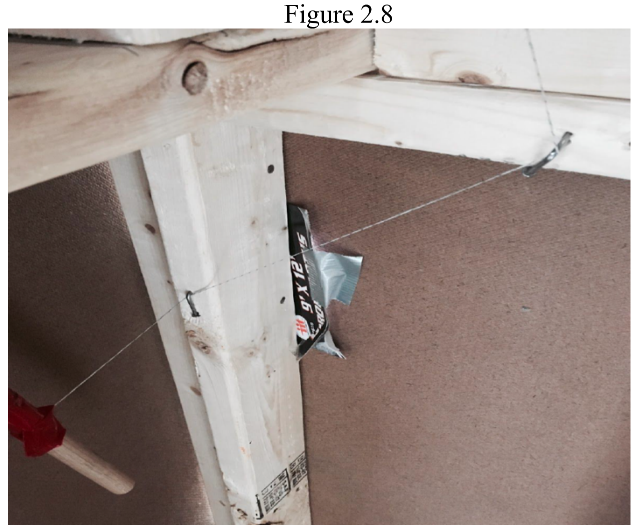
Based on these dimensions it was also decided most appropriate to construct the slot machine in 2 frames. One bottom frame, which would house the chute, hidden panel, lever, and safe, and one top frame which would house the dial-track mechanism and the clue dispenser.

D. Further Decisions for Cost-Reduction

1. Lever-track interaction

The track was later decided to be pulled using a system of pulleys rather than a ratchet-gear system. This was justified by (1) calibration of a pulley system being easier and quicker than gear ratios, allowing trial-and-error testing, and (2) it eliminated the need for laser cutting, thereby significantly reducing cost of the project.

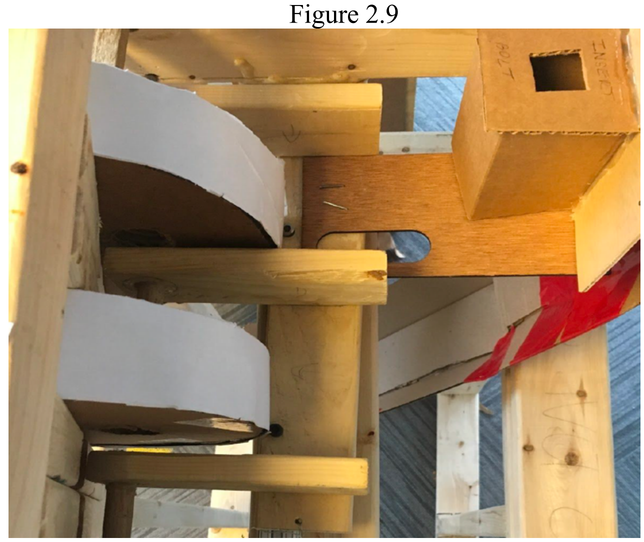
Figure 2.8



2. Clue dispenser

The first design iteration of this component included a panel which would get pulled up, letting an object roll down a track to the user. This was decided to be expensive to implement as the materials visible to the user were required to be of good quality. Instead, the mechanism would be housed inside the machine and constructed with scrap material. A box holds the clue until the track is pulled, pulling the bottom of the box out from under and letting the clue fall onto a chute which redirects it to the slot.

Figure 2.9



3. Dial Material

The dial underwent a few different potential materials. The first design iteration called for wooden dials. However, after identifying this as a significant cost to the team, other options were explored. Below is a table of all materials with their costs and relative advantages.

Table 2.10: Material Costs of Dials

Material	Cost (USD)	Relative Advantage of Material
Wood	20.00	*Sturdy feel, easily painted, strong*
Hamster Wheels	45.00	*Smooth surface, easily painted*
Hardboard	25.00	*Thinner, but very smooth and sturdy*
Cardboard	0.00	*Weaker material, opens possibility of further prototypes*

Hence, it was decided that cardboard was the ideal material for the project. The cost was the most significant factor to consider, but for the purposes of achieving the goals defined in section II, cardboard was not a limiting material. The dials only had to last a total of 8 hours of playtime, which they would easily surpass. In the end, the material was even stronger than first anticipated.

4. Panel Material

The outside of the slot machine was to be covered in paneling that could be decorated to finish the aesthetics of the machine, as discussed in "Track Mechanism and Aesthetics of the Fake Slot Machine" authored by Ramez Mubarak. The original design of the paneling called for hardboard material costing up to $30 per sheet. The team was lucky to be donated left-over scrap boarding used at construction sites to set up temporary walls. The scrap paneling was then spray-painted red and stickers were attached to the front reading "JACKPOT."

Figure 2.11

IV. Ethics and Value Sensitive Design

Value Sensitive Design is the initiative of including moral decisions regarding the designers' and users' values in accomplishing their goals. As a team, value sensitive design remained embedded in the methods of construction and design. There were, however, possible ways in which the escape room could have been improved as to make the room more accessible, address the issue of gambling in a more sensitive manner, and reduce environmental impact.

A. Increasing Accessibility

Increasing the accessibility of the escape room would aim to make it playable by more people. This includes but is not limited to ensuring it is handicap accessible, cheaper or closer to people who cannot afford transportation and targeting it towards a greater age range. One issue that was identified with our escape room was that the props in the room left it fairly inaccessible to differently abled persons or those in wheel-chairs. Further, the room was targeted towards a very small demographic. It was meant to be for college students of ages 18-30. Increasing this age range could mean extending the room to children. This would include slight modifications to the puzzles to make them simpler, or even removal of some puzzles. Whether this applies towards creating a more value sensitive design depends on the values of the teams involved in creating the room. If one of the teams' common values is having a positive impact on the community, letting children of Roxbury and other neighborhoods nearby Northeastern take part in the room would accomplish this goal. However, it may be important to make the room accessible to them by finding a more appropriate venue. Presenting the room at International Village allowed some accessibility as it is close to Northeastern Crossing, a community outreach organization on campus.

B. Addressing the Issue of Gambling

When deciding the theme of the room, the class had a few discussions on whether designing a room on real serial killers would be insensitive to the families of those that were killed by this serial killer. The class decided in unison to avoid this theme, thereby an indication that one of our values is how a room can impact others based on their experiences. Gambling, as glorified as it is through Hollywood and popular culture, is a real and significant issue to many people in Boston. Therefore, addressing this issue may have been an important step in ensuring value sensitive design. One way this issue could have been addressed would have been to include a positive message regarding gambling in the video which introduces the room. For example, the video could have explained that the 'Pennypacker Casino' was shutting down due to its negative impact on poor communities, thereby shedding light on the issue without compromising the theme.

C. Reducing Environmental Impact

This was one of the issues the slot machine team worked well with. The team reduced all trash and spill wood by cutting effectively and using iterative design as opposed to rapid prototyping. Further the group reused scrap material frequently rather than purchasing new materials. The team also saved the project, despite its large size, as a center piece for their apartment next year. However, as a class the goal of reducing environmental impact wasn't met with the same rigor. The infrastructure committee spent 50 dollars on accessories and design of the room to increase the aesthetics of it but trashed most of the materials after their short use. These materials could have instead been collected and reused in other Cornerstone of Engineering sections, therefore leaving a smaller impact on the environment.

V. Infrastructure Sub-Committee Summary

The Infrastructure Sub-Committee was responsible for the interior design and aesthetics of the escape room as a whole. This sub-committee met 7 times to decide on the room used, where puzzles would be placed, color coordination, and purchasing materials using the course budget to improve the aesthetics of the room. Members of the escape room also spent two hours previous to the room opening to prepare and organize all puzzles and decorate the room. The infrastructure team was also in charge of clean-up. The committee abided by the following budget for the interior decoration of the escape room:

Table 3.1 Escape Room Budget

Item	Use	Cost (USD)
Poker Chips	*Put on the floor and on tables*	*6.50*
Cobwebbs	*Hung up around the room to sell 'abandoned' look*	*5.00*
Caution Tape	*Also in theme with the room being 'abandoned' and soon to be demolished*	*4.00*
Prop Money	*Left around the floor, in the safe, and on the walls*	*10.00*
Spray-paint	*Spraypainted the slot machine, as well as a tarp for decoration*	*8.00*
Plastic Tarp	*Covered the slot machine and some other furniture: 'abandoned'*	*7.00*
TOTAL	**-**	***40.50***

VI. Reflection

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A. *Extent of Success*

As discussed in section II. the team had defined 4 parameters for success of the slot machine. They were as follows:

1) The interactive components of the machine should be obvious and function intuitively.

2) The action of pulling the lever should immediately result in auditory response from the next clue being dispensed, as an indication that the puzzle has been solved.

3) The machine should be able to function despite misuse.

4) The slot machine should be a memorable piece to the escape room and should be identified as one of the player's favorite.

The first three of these parameters were tested before the day of the escape room. All 3 parameters were achieved during this testing. However, during transport of the machine, the string on the pulleys snapped. It was therefore necessary to replace it with a different type of string, which was not as strong. Misuse led to this string snapping 4 hours into the day, and a crude replacement had to be fastened, rendering the machine non-functioning for a few hours.

The class collected reflections from each person that completed the escape room in order to better inform the success of the room and the points of improvement. Despite breaking after 4 hours, the slot machine was identified by 4 persons as their favorite puzzle, putting the slot machine as second place to the fan favorite Office Puzzle.

Overall the project was a success. The fabricated object was of high quality and acted as a centerpiece for the decoration of the room. It helped legitimize the room as a 'real' escape room.

B. *Future Improvements*

The most significant and difficult issue to address in creating an escape room seems to be the puzzle progression. It is difficult to create a cohesive room and seamless experience when each puzzle is individually designed and produced by a different set of people. Coordination between the groups is not just an issue of communication but of vision. The sub-committee responsible for puzzle progression, Flow, did a good job of coordinating efforts. To improve this in the future, I think it would be entirely possible to force teams to work closely with the team creating the puzzle that follows them. Thereby the puzzles aren't as modular and take into consideration what will follow. Further, moving beyond the thinking of the room being a set of stand-alone, physical puzzles but rather interact with the space itself would help integrate the user experience. The office did a good job with this and is likely why it was such a fan favorite. Lastly, removing some puzzles may have been helpful to the difficulty of the escape room and achieving close to the 60-minute window which the room set out to take.

Acknowledgment

This project's success owes a great deal to the professor of the section, Mark Sivak PhD. We thank him for his assistance in not only evaluating individual design decisions but for all his help in defining the steps of the design process of this project and his continued mentoring throughout the entire year. Further I would like to personally thank the rest of my team members for their contributions and hard work. The quality of our fabricated object was entirely due to the team's hard work. I know it is not easy to allocate 40 hours of work to a project soon before finals, and I appreciate the dedication of my team members to achieve quality rather than the bare minimum.