



## Designing a MATLAB-based Escape Room

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## Abstract

Escape rooms promote creative thinking, teamwork, communication, and cooperation, making them valuable tools for educational applications. However, physical escape rooms can be expensive to construct, impractical for temporary use, and difficult to adapt for large classes. To address these limitations, we designed a MATLAB-based escape room for BME 303L: Modern Diagnostic Imaging Systems. BME 303L is generally comprised of approximately 70 undergraduate biomedical engineering students at Duke University each spring. This upper-level core class, taken by juniors and seniors, covers the mathematical and physical bases underlying medical imaging modalities including x-ray, computed tomography (CT), ultrasound, magnetic resonance imaging (MRI), and nuclear medicine.

MATLAB was specifically selected as the interface for this activity as it is:

- Windows-, Mac-, and Linux-compatible
- Freely available on almost all university- and student-owned computers
- Fully customizable due to its built-in graphical user interface (GUI) tools
- Able to accommodate large numbers of students/teams
- Easily modifiable, adaptable, and transferrable
- Able to automatically keep time and assess penalties
- Able to randomize aspects of room puzzles

The escape room was comprised of 6 rooms, each of which corresponded to a single course module. The puzzle(s) within each room were specifically designed to align with the student learning outcomes of each module and to test a broad range of concepts within each imaging modality. After reviewing the game rules and starting the countdown timer, the students chose a room from a drop-down menu. An image of the “room” was then displayed within the MATLAB GUI. As is customary in escape rooms, students had to identify both the question being asked and the answer to that question in order to determine the “secret code” (consisting of three letters or numbers) required to escape the room. When the students solved the final room puzzle, the program immediately stopped and computed the time it took each team to escape. Two hints and a solution card were available for each room; however, each hint added a time penalty (in minutes) equal to the total number of hints/solution cards used to the elapsed time. Additionally, a 30-second time penalty was assessed for each incorrect answer. Students were provided with a formula sheet, and were encouraged to use a calculator, blank paper, and writing utensils.

The class consisted of 17 teams of 3-4 students. All teams successfully escaped all 6 rooms in an average (h:mm:ss) of 0:43:50 [range: 0:14:30-1:07:28]. Very few groups used hints, as most students did not want to be assessed a time penalty. None of the teams used a solution card to automatically bypass a room without solving the puzzle.

Our MATLAB-based escape room challenged students to work together to recall concepts from each course module, which enabled them to identify topics they needed to review more closely in anticipation of the cumulative final exam. While this escape room was designed specifically for a medical imaging course, the MATLAB framework developed for this activity can be readily

adapted to address the specific needs of a variety of courses. For example, additional rooms can be added, the difficulty level of each puzzle can be modified, time penalties can be changed or removed, additional hints can be provided, etc. Educators can use this framework to not only supplement classroom learning and recall in a fun and engaging way, but they can also use it to promote the development of intangible engineering skills, including communication, curiosity, time management, and teamwork.

### **Motivation for Escape Room Activity**

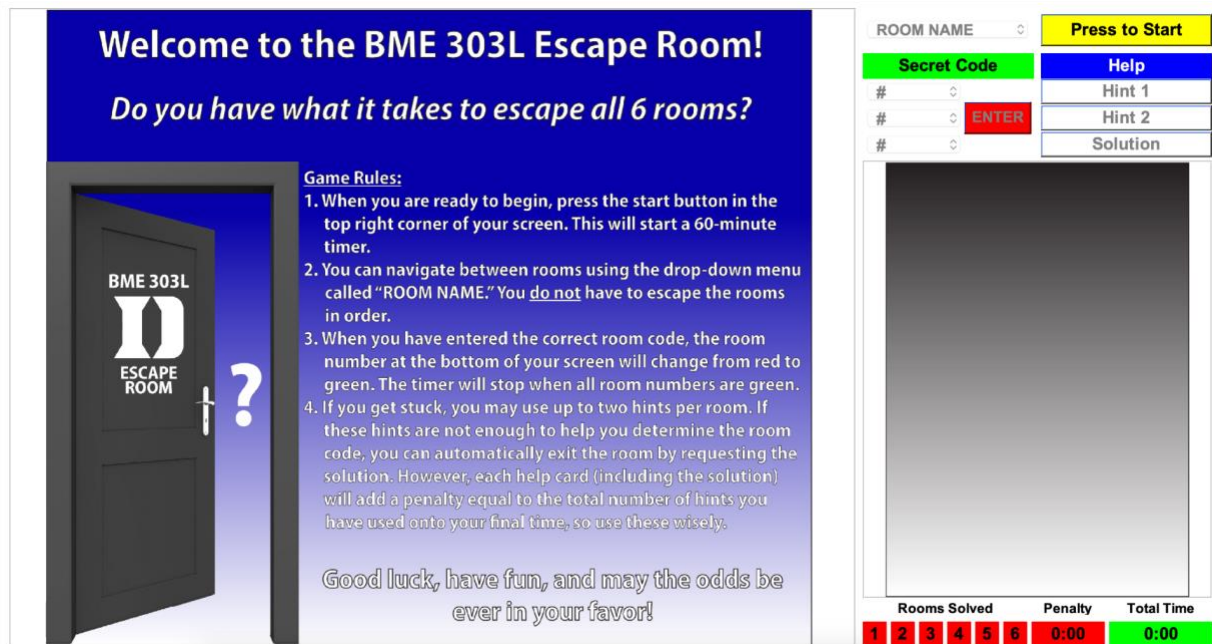
Escape rooms have seen unprecedented growth worldwide over the last few years, appearing almost overnight in just about every US city [1]. People are lining up and paying to be “locked” inside of a room where they must work collaboratively in small teams and use critical thinking to solve a series of puzzles to “escape” before time expires [1]. Masses of people are getting excited to solve problems, which has caught the attention of educators [2-4]. Classroom games have been previously shown to increase student engagement, learning, and motivation [2, 3, 5]. Therefore, implementing escape rooms in educational settings can serve as a powerful learning tool.

We sought to create a course-specific escape room activity for advanced undergraduate biomedical engineering students in BME 303L: Modern Diagnostic Imaging Systems at Duke University. This upper-level core class covers the mathematical and physical bases of various medical imaging modalities, and it is comprised of six course modules: (1) signals and systems, (2) x-ray imaging, (3) computed tomography (CT) imaging, (4) ultrasound imaging, (5) magnetic resonance imaging (MRI), and (6) nuclear medicine. The escape room was designed to serve as a collaborative and fun review exercise to prepare students for their imminent cumulative final exam.

### **Escape Room Development**

While most professional escape rooms provide fully immersive environments, this is generally impractical at schools and universities due to space requirements and expenses. Furthermore, many escape rooms are designed to be attempted by small teams, and they need to be reset between groups. This poses a problem for educators of large classes, who routinely have a narrow timeframe to complete a lesson with all students.

To address these concerns, we created a virtual escape room using MATLAB (The MathWorks, Inc.; Natick, MA). MATLAB was chosen as the interface for this activity due to its built-in features, versatility, and availability. Specifically, in addition to being Windows-, Mac-, and Linux-compatible, MATLAB is freely accessible on almost all university- and student-owned computers, allowing for a large number of student teams to participate simultaneously. Furthermore, its built-in graphical user interface (GUI) tools provide a fully customizable user-friendly display, and it is easily modifiable, adaptable, and transferrable for use in different classes or for varying topics. As an added benefit, our MATLAB-based escape room is able to automatically keep track of the elapsed time, assess time penalties for incorrect answers and the use of hint or solution cards, and randomize room puzzles to decrease the likelihood that neighboring teams have identical puzzles to solve.



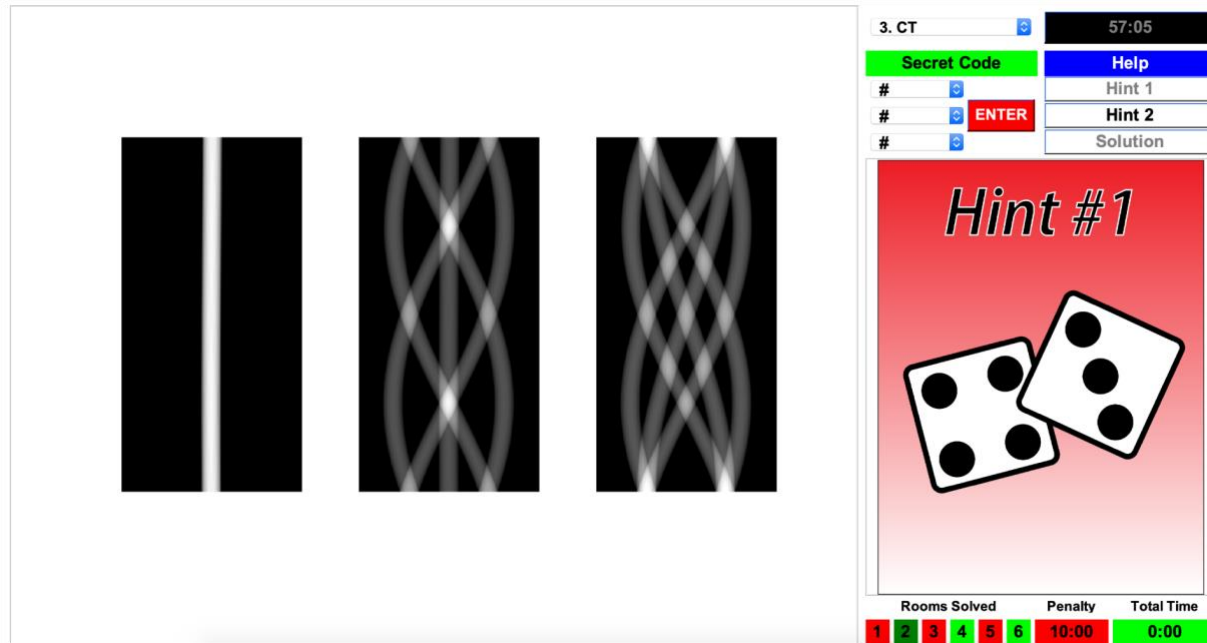
**Figure 1.** Start screen of escape room GUI. The top portion of the GUI consists of a drop-down menu to view room options, a keypad to enter room solution (secret code), a countdown timer which shows students time remaining in their allotted hour, and buttons to request up to two hint cards and one solution card for each room in case students need extra support (cards are displayed in the gray box). The bottom portion of the GUI indicates which rooms have been solved (red = unsolved, lime green = solved traditionally, dark green = solved using solution card), the cumulative time penalties accrued (incorrect answers result in a 30-second time penalty, while hint and solution cards add a penalty equal to the number of these cards used), and the total time taken to complete the game, including any time penalties.

The start screen of the escape room GUI can be seen in **Figure 1**. Students were instructed to read the game rules carefully prior to beginning the game. Once they press the yellow start button, a countdown timer begins. A countdown timer was chosen, as it more closely mimics the experience of commercial escape rooms and test-taking environments. After the timer starts, the students can then proceed to any of the six rooms via the room name drop-down menu. Each room corresponded to a different course module, and the puzzle(s) in each room were designed to directly align with the posted student learning outcomes for each module. After selecting a room, a puzzle corresponding to the chosen room replaces the game rules panel (an example of the computed tomography (CT) puzzle is displayed in **Figure 2**). The students then need to identify both the question being asked as well as the solution to the question in order to determine the secret code. Each incorrect answer entered incurs a 30-second time penalty. Two hint cards and one solution card are available in each room; however, using any of these cards results in an added time penalty equal to the number of help cards ( $M$ ) used:

$$\text{Time Penalty} = \sum_{n=1}^M n$$

For example, if a group chose to use three help cards, a penalty of  $1 + 2 + 3 = 6$  minutes would be added to their total time. This system of increasing penalties was designed to discourage the

use of help cards, as we wanted students to exhaust their collaborative efforts and critical thinking skills prior to opting for additional help. The penalty time accrued from incorrect answers and the use of help cards is tracked in the lower right corner of the game window. Once a specific room is solved, the corresponding room number in the rooms solved panel turns from red to green. Lime green indicates the room puzzle was solved traditionally, while dark green indicates the students used a solution card to bypass the puzzle. When all 6 rooms have been successfully escaped, the countdown timer immediately stops, and the program computes the total time, including the added penalty time. Students were then prompted to notify the instructor that they had finished so their total time could be recorded.

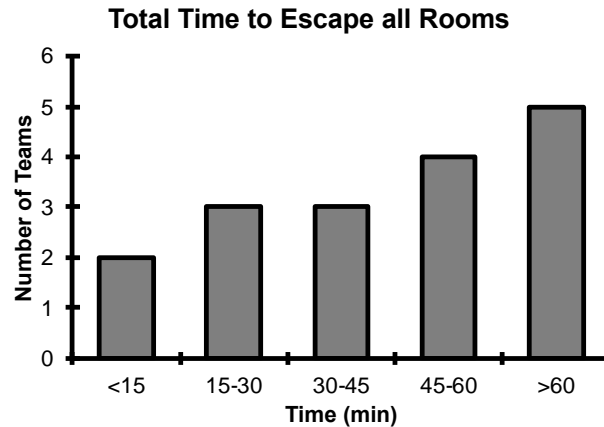


**Figure 2.** Example computed tomography (CT) puzzle with hint #1 shown. This puzzle tests students’ knowledge of sinograms, as each panel is the sinogram of a single side of a standard six-sided die. The solution to this puzzle is 1-5-6.

## Implementation and Assessment of Escape Room

The escape room MATLAB code was pre-loaded on numerous computers within a university computer lab, which was reserved for the duration of the exercise on a single afternoon. Students arrived for a designated one-hour period, during which they divided themselves into teams of 3-4 students. They were asked to please not share details of the game or the puzzles with their classmates until everyone completed the activity. The students were provided with a previous year’s final exam formula sheet and blank paper, and they were encouraged to use writing utensils and calculators. They were also permitted to reference their course notes, as needed.

In total, 17 groups completed the entire escape room in an average (h:mm:ss) of 0:43:50 [range: 0:14:30-1:07:28] (**Figure 3**). During this initial implementation of the game, students were not assessed a time penalty for incorrect answers, which may have decreased the average escape time. As the penalty time was a strong deterrent against using hint cards, only a few groups opted to use any, and no groups used the solution card to bypass solving the room puzzle on their own.



**Figure 3.** Seventeen student teams successfully escaped all 6 puzzle rooms in an average (h:mm:ss) of 0:43:50 [range: 0:14:30-1:07:28].

Students received a participation grade for completing the escape room activity. They were not rewarded based on performance; however, the students were unaware exactly how they would be evaluated prior to the activity. This likely had a positive impact on their desire to escape as quickly as possible without using help cards.

In order to determine whether the escape room activity improved student outcomes, the same final exam was given in Spring 2018 (without escape room) and 2019 (with escape room). Students earned mean ( $\pm$  standard deviation) scores of  $80.3 \pm 8.6$  and  $82.4 \pm 9.2$  in Spring 2018 and 2019, respectively. Although the mean final exam score increased by 2.1 points, this difference was not statistically significant via a t-test ( $p = 0.25$ ). This was not an overly surprising finding, as the escape room was just the latest addition to a variety of pre-existing activities used each semester to actively prepare students for their final exam.

## Conclusion

This escape room activity allowed students to review relevant course material in a competitive, yet low-risk situation prior to their cumulative final exam. The game environment stressed teamwork, communication, cooperation, and critical thinking skills, as each group worked to complete all of the puzzles. While there is research stating that instructor-formed groups outperform self-formed groups, on average, we allowed our students to work with whom they pleased [6]. Future iterations of this activity may involve instructor-formed teams to determine how team formation strategies impact student performance. Furthermore, this activity challenged students to recall information from early in the semester, which ultimately helped them identify areas they needed to focus on more heavily when studying. In general, the students enjoyed competing against their peers to see who could escape the fastest, and they were amazed that the entire game was created using MATLAB. We also invited all former BME 303L students from Spring 2018 to come and try their luck at escaping just for fun. Six former students obliged despite being a year removed from the course and only weeks away from graduating, which was a testament to the excitement surrounding this novel activity. Overall, while some students were frustrated trying to remember concepts they learned a few months prior, they were relieved to

realize how much they were able to recall and what they may have forgotten a full two weeks prior to their final exam.

Although this exercise was constructed specifically for use in an upper-level medical imaging course, our MATLAB-based escape room serves as a general framework for other in-class escape room activities. Due to its versatility, this framework can be readily adapted to suit the needs of educators of a variety of subjects, levels, and even departments. The game can be modified to increase or decrease the difficulty by using custom puzzles, the time penalties can be changed or removed, additional (or fewer) rooms can be included, etc. With this framework, educators can introduce a fun group activity into their curriculum, which can increase student motivation, engagement, and retention, while also bolstering engineering intangibles including communication, teamwork, curiosity, peer-to-peer learning, and time management. The source codes for this activity can be accessed online at [this link](#).

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