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Enhancing Engagement using Educational Escape Rooms for teaching Measurement and Instrumentation

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ABSTRACT

CONTEXT

Measuring the world around us and integrating measurement into designs and control systems are fundamental procedures carried out by many varieties of engineers. We teach a 3rd year Measurement and Instrumentation subject, covering calibration, noise reduction and a wide breadth of sensor technologies, using traditional teaching modality (lecture and laboratories). In this study, we apply the use of an educational escape room (EER), where domain knowledge and problem-solving is woven within a series of collaborative themed puzzles. EERs have been demonstrated to improve student engagement and facilitate team-based problem-solving.

PURPOSE OR GOAL

The current student cohort is diverse, consisting of both civil engineers and industrial engineers, which has in the past led to some contention concerning the value of the subject for their specific discipline. This contention in the past has led some students to disengage and was accompanied by poor student feedback. Hence, along with revising the subject, we wanted to introduce hands-on, problem-solving activities to strongly engage students.

APPROACH OR METHODOLOGY/METHODS

An escape room was designed consisting of three multi-step puzzles and a supervillain storyline. The respective puzzles focus on linear calibration, Fourier transforms and inferring motion from a time-of-flight sensor. After alpha testing our EER with a staff member, we applied the EER within a face-to-face laboratory classroom using a table-top electronic decoder box to validate student solutions, perform timekeeping and provide clues. Data from student progression (time taken for each puzzle and incorrect guesses) along with post-activity Likert surveys were used to quantify the effectiveness of the activity.

ACTUAL OR ANTICIPATED OUTCOMES

The activity was well received by students with an average score of 4.4/5 for students “wanting to complete the activity”, 4.1/5 on students “agreeing it improved the subject” and 4.2/5, 4.0/5 and 3.6/5 for student enjoyment of the respective puzzles. Students completed the EER in groups of three or four. There were an average number of 6.3 incorrect guesses per group (each of which incurred a one-minute time penalty) with two groups (out of 10) making no incorrect guesses.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

EERs are proving to be an effective game-based learning pedagogy to engage students and encourage team-based problem-solving. This is the first published EER relating to measurement and sensor systems for an engineering course. The feedback from in-class testing with our cohort of 40 students will serve as a basis to create educational escape rooms within our subject to enhance student engagement and collaborative problem-solving.

KEYWORDS

Game-based Learning, Gamification, Educational Escape Room

Introduction

In contrast to what was considered a 'traditional University learning experience' (i.e. lectures and laboratory experiments), the modern University classroom may be augmented with many different learning pedagogies including flipped classrooms, active learning, and gamification. One recent innovation has been the use of Educational Escape Rooms (EERs) to strongly engage students in collaborative problem-solving activities.

EERs take their inspiration from recreational escape rooms, where teams of willing participants are 'locked' in themed rooms full of puzzles which need to be collaboratively solved before a time limit expires. Recreational escape rooms originated in Japan around 2007 and quickly spread around the world as popular tourist attractions along with being used for corporate team-building, date nights and family activities (Nicholson, 2015; Wiemker et al., 2015).

Less than a decade after the first recreational escape room, experimentation with EERs began in classrooms (Eukel et al., 2017; Nicholson, 2018; Vörös & Sárközi, 2017). Traditional recreational escape rooms don't scale particularly well to the classroom where there may be large numbers of students and not a whole series of small rooms which can be set up for each group of students. Hence, many educational escape rooms have either taken a virtual form or a tabletop form.

Virtual escape rooms have been run with varying degrees of sophistication including the use of Google Forms or spreadsheets through to purpose-built websites which deliver puzzles, clues, timekeeping and track player progress (Ang et al., 2020; López-Pernas et al., 2021). In contrast, table-top escape rooms are less abstracted using lockboxes (with combination locks) or electronic decoder boxes to validate solutions (Nicholson, 2018; Ross et al., 2023).

Educational escape rooms have been successfully used across all levels of education from primary school through to university education. Within university education EERs have been used across a wide breadth of domains including medicine, chemistry, computer science and engineering (Adams et al., 2018; Guckian et al., 2020; Hacke, 2019; Ross et al., 2021). The literature evaluating EERs has reported a significant positive impact on student engagement, peer learning, and a student preference for these approaches compared to more traditional problem-solving tasks (Guckian et al., 2020; López-Pernas et al., 2019).

The escape room described in this paper is for a third-year measurement and instrumentation engineering subject. The subject is a common unit taught to industrial engineering students and civil engineering students covering a wide variety of sensors, digital sampling systems, calibration and fundamental concepts around signal processing to improve sensor data. The subject is taught using pre-recorded chroma-keyed video lectures and weekly 3-hour practical laboratories which are heavily based on the calibration and testing a variety of sensors in different conditions and with different sensing artefacts. The subject had some previous concerns around appropriateness for spanning the diverse cohort of students, so in addition to a recalibration of lecture topics, the inclusion of an escape room was taken as an opportunity to emphasise collaborative problem-solving and to enhance student engagement in the subject content.

This paper is structured as follows: First, the theme, format and puzzles of the escape room are described. Following this, feedback from the escape room in terms of analytics data and survey data is presented and discussed. Finally, findings are summarized along with suggestions on how this escape room is likely to be used in the future.

Methodology

Educational Escape Rooms are forms of game-based learning comprising of a story-line, puzzles and some form of puzzle validation (e.g. locks or decoder boxes). This section first outlines the progressive thematic narrative which ties the activity together, followed by details of how the escape room was conducted, and then finally by the three puzzles which students need to solve for each stage to complete the escape room activity.

Narrative/Storyline

The choice of narrative offers up vast possibilities with diverse themes ranging from zombie apocalypses and space station security protocols through to jail breaks and mysteries (Nicholson, 2018). Typically, themes include three main elements: some context to the problems, some tension that needs to be resolved (e.g. unlocking locks) and some timing context to provide some urgency to the activity (Nicholson, 2018; Ross et al., 2023). A superhero/villain narrative was chosen for this escape room activity and was woven as a progressive narrative throughout the three puzzles. The narrative helps tie the puzzles together as a cohesive game rather than disjointed exam questions. Before students are presented with the puzzles, they were given the following introduction in written form:

Normally your work at Wayne Enterprises relates to creating cool new tech for your boss, none other than the caped crusader. But with Mr Wayne currently accompanying Elon Musk for a joyride to the moon, your team has been called in to try and capture the Enigma. The Enigma is a criminal mastermind and is believed to be a first cousin of the Riddler who Batman took care of a decade ago.

Your team have just managed to infiltrate the building that is believed to be the Enigmas hide-out. The building blueprints (which your team hacked from the server last week) seem to indicate that there are three levels of security before you make your way into the Enigmas' private lair. It seems each of these layers has some sort of a puzzle which needs to be solved before you can apprehend this devious villain.

Armed with a toolkit, sensors and your wits you open the first envelope (which is the first security puzzle). Radio chatter you managed to pick up indicates that the next security patrol will be by in 45 minutes, but wrong guesses might trigger some sort of alarm (so they will be penalised by 1 minute). You can only work on one puzzle at a time as you move through each of the security checkpoints.

Game Dynamics

Besides outlining a theme and context for the puzzles, the introductory analysis also provides four elements which are relevant to the game dynamics. Firstly, it provides reasoning for a time-limit of 45 minutes in which the puzzles need to be solved. Secondly, it provides detail about penalties that are applied for incorrect guesses as puzzles are solved. Thirdly, it highlights that puzzles need to be completed sequentially and one at a time. Finally, it provides context for three layers of puzzles which need to be solved for the escape room to be completed.

Before using the escape rooms in the classroom they were alpha tested with another academic who was not involved in writing the escape room. This alpha testing helps ensure that the solutions for the escape room were correct and that without prior knowledge of how the puzzles work they could be solvable given sufficient knowledge about the discipline that was being tested.

Within the classroom, students were grouped in groups of three or four and sat together around tables which allowed them to collaborate as they solve the puzzles. During the escape room activities students had access to computers, lecture notes and the Internet which they may be able to draw upon to solve problems. Each of the puzzles was printed out and put in a separate sealed envelope labelled 1, 2 and 3.

An escape room decoder box was used to provide validation of student answers, timekeeping, and to provide clues along the way (Ross, 2019). Additionally, the decoder box also penalises wrong guesses with a one-minute penalty and records analytics of student progress in terms of time taken to solve each puzzle and incorrect guesses for each puzzle. The decoder box was programmed to automatically provide the participants with a clue at 5-minute intervals (in the form of the next number sequence in the puzzle being revealed).

After the activity was completed students completed a post-activity survey. Students were questioned on puzzle enjoyment, difficulty and Likert questions to measure engagement, flow and teamwork. All surveys were anonymous, though each survey form was assigned a team number so that survey responses within a team could be compared and responses could be correlated to the analytics collected from each of the decoder boxes. No details about which students were in which teams were collected or stored.

Puzzle 1 (Time/Frequency Domain)

The first puzzle allows students to perform reasoning between the time and frequency domain in a graphical form. Concepts of sampling rates, signal processing and frequency analysis are foundational to measurement systems and so are formulated as a matching exercise between the time domain and frequency domain for each of these puzzles. Each of the puzzles included some more of a progressive narrative which helps provide context to the puzzle followed by the puzzle itself.

The puzzle presented in this paper is a partial puzzle both for brevity and so that the full solution isn't revealed to industrious students who may read the paper. Our full puzzle includes five time domain waveforms which need to be matched with five frequency domain waveforms.

As you enter the first security checkpoint you spot on one wall what seems to be some plots of 5 signals where the magnitude of the signal is changing over time. On the table you notice 5 whistles (labelled 1, 2, 3, 4 and 5). As you blow on each whistle you notice they all sound a bit different.

One of your teammates whips out their phone and uses a spectrum analyser to look at the frequency characteristics of each signal. Maybe you need to somehow match the whistles to the plots so they can be blown in the correct order to solve the Enigma's first riddle.

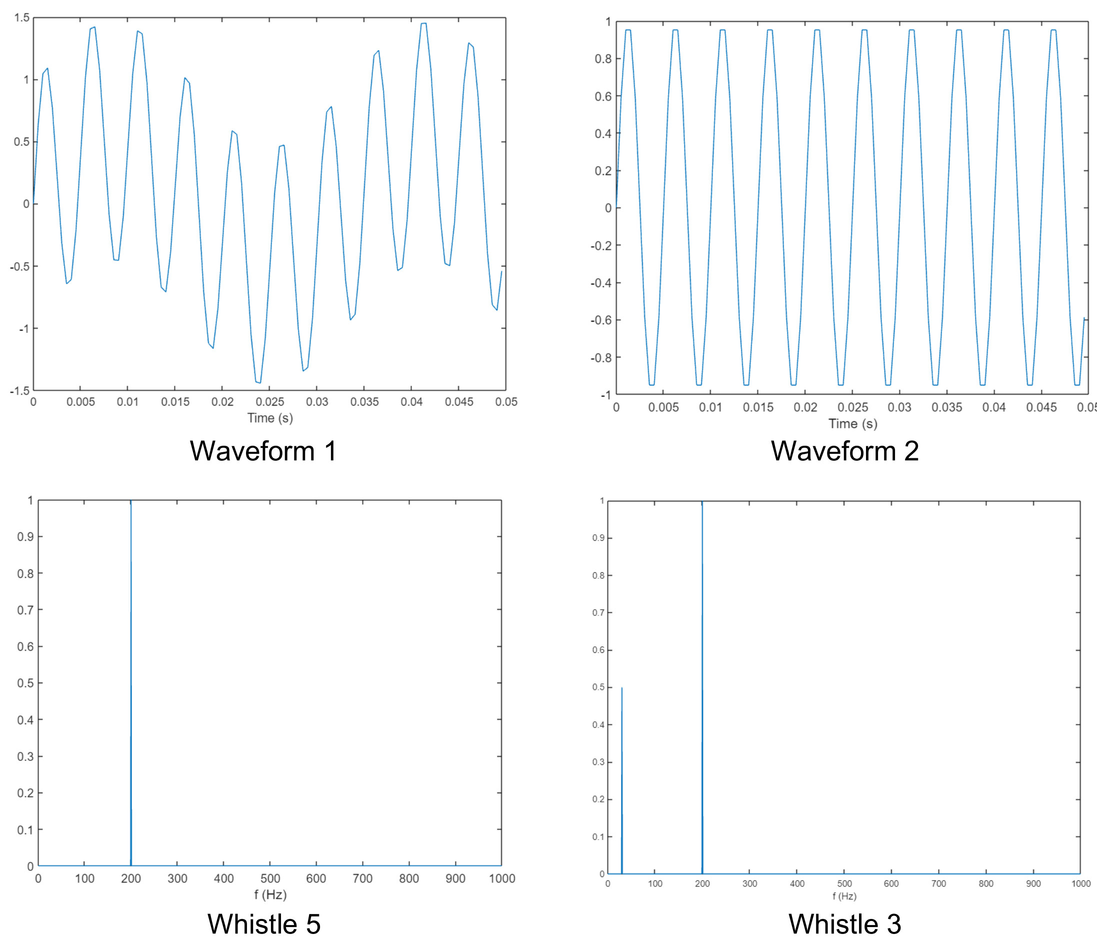


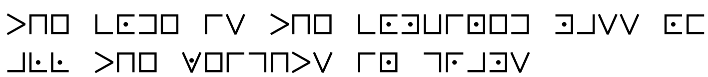
Figure 1: Subset of frequency and time domain waveforms for Puzzle 1

In the example in Figure 1, waveform 1 matches the frequency spectrum for whistle 3, and waveform 2 matches whistle 5. Hence, the first two digits of the code would be 35. Once students enter all 5 correct digits into the decoder box a success message is displayed which indicates to students that they can move on to the second puzzle.

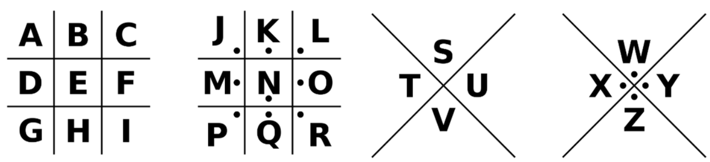
Puzzle 2 (Calibration)

Another fundamental task carried out when studying sensors is to calibrate sensors against known quantities. For example, when sensors are connected to an ADC (Analogue to Digital Converter) the quantized values measured needs to be calibrated so that they can be converted into a real-world physical quantity (e.g. grams, velocity or force). Puzzle two starts with some basic decoding of a clue using a pigpen cypher followed by calibrating a load cell and hence working out unknown weights using quantized data. Additional unknown weights are used to make the problem more substantial for students solving the puzzles.

You congratulate each other on passing that first security checkpoint. As you enter the second security checkpoint you notice a series of weights stacked on the table. Next to the keypad you see a series of scratching on the wall as follows:



It's a good thing you came prepared and brought along a pig-pen cipher decryption key:



As you look at weights you realise that only two of them have a value written on them (Weight A is 50g, Weight B is 200g). As you survey the room you notice a small set of digital scales with a busted LCD screen. You quickly whip off the cover and connect an Arduino up to the load cells inside. As your team-mates decode the message you quickly get to work weighing each of the weights individually and compile the following table:

Weights	ADC Value
Weight A (50g)	2245
Weight B (200g)	2920
Weight C (Unknown)	4045
Weight D (Unknown)	3010

Figure 2: Subset of Puzzle 2 relating to calibration of a load cell.

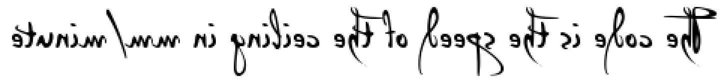
When the students use the pigpen cypher to decode the message the result they get is as follows: "The code is the combined mass of all the weights in grams". To solve this puzzle students would be expected to use some software like MATLAB or Excel to plot known weights and ADC values, create a line of best fit, and hence solve unknown weights.

Puzzle 3 (Time of Flight)

One common sensor used within laboratory classes is a time-of-flight-based SONAR sensor. These sensors produce a chirp of ultrasonic sound which bounces off distant objects and this returns to the sensor. To measure the distance from these distant objects the time taken for the echo of the sound to be received is measured. Rather than simply computing a few distances which is relatively trivial, this puzzle requires students to compute a rate of change based on distance captured taken at different intervals.

As you enter the final security checkpoint you hear a faint sound of some mechanical gears. As you look up it seems the ceiling is very slowly moving downwards. At this rate you will be a team of pancakes in a matter of minutes.

A message is scrawled onto the wall next to the keypad (presumably in case the Enigma forgot what the code was).



As you decode the writing one of your team postulates maybe the code has something to do with the motion of the ceiling. You pull out your ultrasonic rangefinder but find it is stuck on a mode which doesn't give you distance but time taken for the signal to be sent and received (in ms). As it feels about 20^{o}C, the speed of sound should be about 343 m/s.

Your first measurement of the ceiling is 17.44 ms. Exactly 40 seconds later you take another measurement and it is now 16.60 ms. You try and nut out this last problem to apprehend the enigma and also to avoid feeling flat.

Figure 3: Puzzle 3 relating to ultrasonic rangefinder computation

Students can either use a mirror or hold the piece of paper up to a light in reverse to read the mirror writing which reads "The code is the speed of the ceiling in mm/minute". Remembering that the distance is doubled (as signals need to travel to distant objects and bounce back), students should calculate the distances as 2.99096 m and 2.8469 m respectively. As the measurements are captured 40 s apart the velocity of the ceiling can be computed as 216 mm/minute.

Results and Evaluation

This section first presents the quantitative results collected as analytics from the decoder boxes followed by the survey results that students completed post the activity. A total of 9 groups completed the escape room with Figure 4 showing the time taken for each group to complete each of the puzzles. Three groups (5, 7 and 9) inadvertently (or deliberately) reset their decoder boxes during the activity (by switching the key on and off) and so timing for Puzzle 1 (and Puzzle 2 for group 5) is unavailable for these groups. Two Groups (3 and 6) don't have a recorded time for puzzle three as they didn't complete Puzzle 3 within the allocated time. For the recorded data students completed Puzzle 1 fastest (471 seconds average), followed by Puzzle 3 (758 seconds average) with Puzzle 2 taking the longest (988 seconds average).

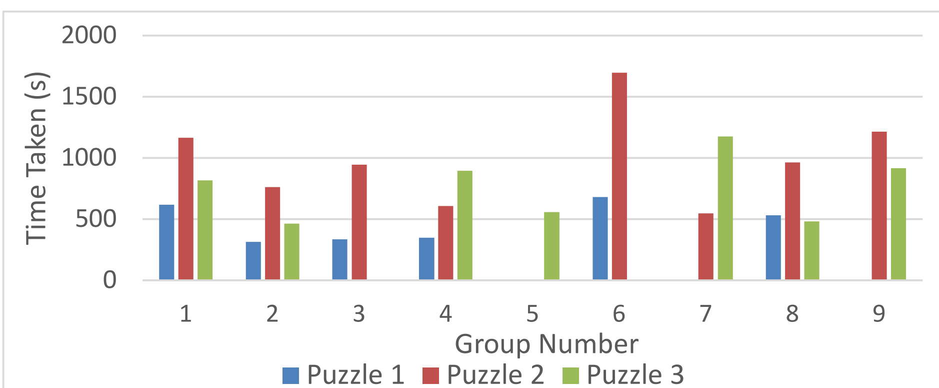


Figure 4: Breakdown of time taken for each puzzle

Analytics were also collected for the number of incorrect guesses made for each puzzle as shown in Figure 5. The incorrect guess data highlights that different groups of students took different approaches to solving problems. Groups were penalised with a 1-minute penalty for each incorrect guess and so different groups seemed to have a different approach to risk within the activity. Groups which didn't successfully complete the activity (3 and 6) recorded a significant number of incorrect guesses. Incorrect guess data is unavailable for groups 5, 7 and 9 for Puzzle 1 due to the reset of these boxes. Hence, only group 2 definitively had zero incorrect guesses and this group also had the fastest completion time for the activity (1534 seconds) which shows the benefit of them knowing what they were doing and not suffering from time penalties.

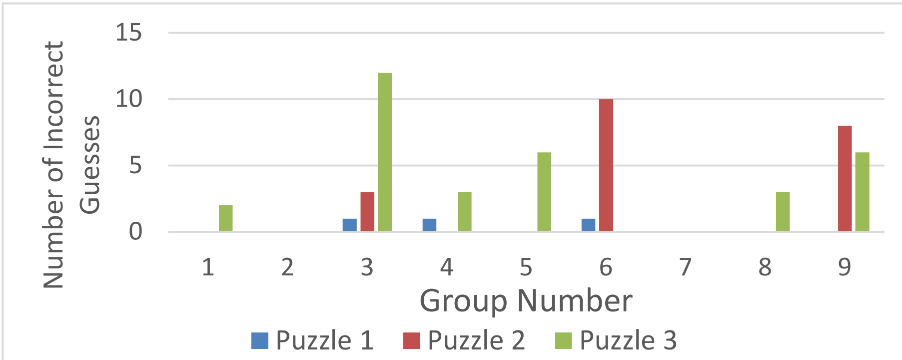


Figure 5: Breakdown of number of incorrect guesses made for each puzzle

Figure 6 shows student survey related to how they enjoyed each of the puzzles. Overall, the enjoyment across the puzzles was high, although the enjoyment was slightly reduced for the third puzzle with a few participants responding 'not fun' and 'very not fun'. The two participants who recorded puzzle 3 as 'very not fun' were both in the same team (group 8) and their two team-mates recorded puzzle 3 as 'very fun' and 'fun' respectively. The two students who answered 'very not fun' answered either 'very fun' or 'fun' for puzzles one and two which suggests that rather than disliking the entire activity, possibly factors of an impending deadline attenuated their enjoyment. One possible fix would be to slightly increase the time (e.g. an extra 5 minutes) for the activity so that students don't find they are rushing as much through the final puzzle.

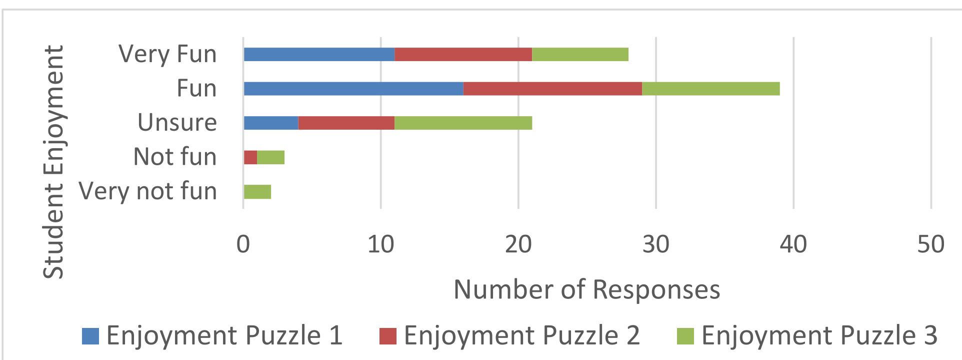


Figure 6: Student data on enjoyment for each puzzle

The enjoyment question was answered without context (enjoyment in comparison to what). It is expected that most students ranked their enjoyment in contrast to other typical class activities (labs, lectures, exams) rather than something more intrinsically enjoyable (e.g. visiting SeaWorld or playing video games). The vast majority of the students enjoyed most of the puzzles.

Figure 7 shows student ranking of the difficulty of the puzzles. Puzzles were ranked progressively harder from Puzzle 1 through to Puzzle 3, which may also be confounded by a sense of time running out. There is a wide spread of feedback related to the difficulty of the activity and difficult puzzles aren't necessarily a bad thing provided students can rise to the challenge.

Table 1 shows four additional questions students were surveyed on which didn't specifically relate to a particular puzzle. Question 1 shows a high degree of agreement with only one 'disagree' and 6 'unsure' responses. Question 2 shows the lowest standard deviation where students had a strong belief that they collaborated well with their team. Students were given the flexibility to select their teams and so this mean may be been lower if teams were assigned.

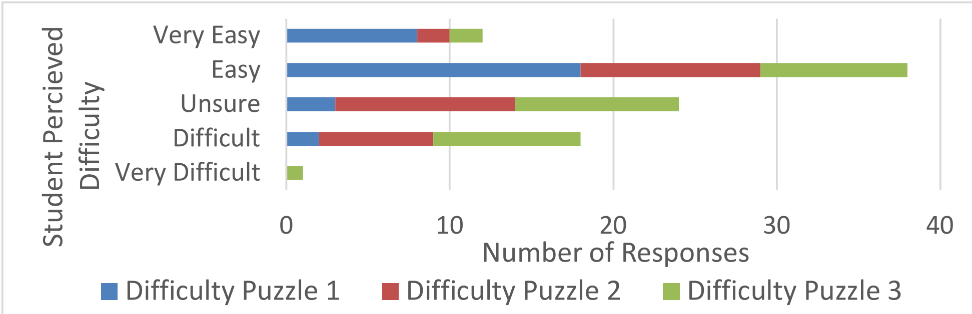


Figure 7: Student data on difficulty for each puzzle

Question 3 had the lowest level of agreement (although still relatively high) and the highest standard deviation. This suggests that some students likely experienced a state of flow (where they are blocking out distractions and are focused on the problem) and other students didn't or at least didn't want to admit they were unaware of their surroundings. Finally, Question 4 demonstrates a high degree of agreement (with no 'disagree' or 'strongly disagree' responses) that students wanted to complete the activity – demonstrating a high degree of intrinsic motivation. The overall satisfaction for the subject improved from a very low score of 2.4/5 to 3.8/5. As the subject underwent a major revision in 2023 (including labs, lectures and escape room) this improvement can't be attributed to the escape room alone although there were several positive comments in the student feedback relating to the escape room.

Table 1: Likert survey questions

Question	Mean (Likert 1-5)	Standard Deviation
Q1. This activity improves EMS3001?	4.1	0.8
Q2. I collaborated well with my team during the escape room activity?	4.4	0.6
Q3. I became unaware of my surroundings while doing the escape room activity?	3.6	1.2
Q4. I wanted to complete the escape room activity?	4.4	0.8

The cohort of students in this class was a mixed group of engineering students, some of whom would have completed escape room activities previously and some who had not. The precise makeup of the different escape room teams was not recorded so inferences on prior experience with escape rooms and performance cannot be drawn. For future escape rooms a short, generic instructional video will be created which briefly explains what escape rooms are, strategies for solving puzzles (especially in terms of looking for a series of numbers), understanding time penalties, effective teamwork and using provided clues. Such a video could be provided to students in each new subject where escape rooms are used to give new students some background and more experienced students a refresher on how educational escape rooms work.

The escape room activity was designed to augment traditional teaching modalities (laboratories and online lectures) but there are too many confounding factors (complete subject re-write and COVID lockdown variations in preparedness) to reasonably compare student outcomes between cohorts.

Conclusion

Educational Escape Rooms are proving to be an effective pedagogical approach to engage students in collaborative active learning across many disciplines. This pioneering escape room was well received by students who were very motivated to complete the activity even though no marks were attached to the activity. Given the vast majority of students enjoyed the puzzles and agreed that the escape room was ‘a positive improvement to the subject’ there is a strong case for repeating the activity and adding some additional escape rooms within the subject as the current escape room only covers approximately 20% of the subject content.

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