Gamification of Engineering Exam Revision using Escape Rooms

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Introduction

For better or worse, exams are a major component of undergraduate Engineering assessment (Wellington, Thomas, Powell, & Clarke, 2002) and are a significant source of stress for students (Parsons, 2008). With many exams often held in a short period of time, students who want to do well on exams need to be strategic about what material they choose to spend their study time on (Ames & Archer, 1988). Students who are motivated by mastery-avoidance goals (Richey, Nokes-Malach, & Wallace, 2014) may see lectures on exam revision as crucial in targeting their effort towards material that they believe likely to appear on the exam. Rightly or wrongly, most students attend and pay very close attention in these exam revision sessions.

Exams are to some extent, arguably, a kind of a game. Let's briefly entertain the analogy. There are levels, within and between exams. As the levels go up, the monsters get more challenging to beat. Players acquire scores that can be ranked. Under a broad definition of a *game* which states that an activity needs to have at least one game component, an exam can be considered a game. However the breadth of this definition has been contested (Deterding, Dixon, Khaled, & Nacke, 2011). Most students do not find exam taking fun in the slightest, and many universities require an ethics application to publish student exam results which could (but is not allowed to) be used to construct a leader-board. The argument has little force.

Nevertheless, serious games, that is, games designed to convey educational material, have been around since the dawn of time in the form of war gaming (Halter, 2006). Business simulation games have been around since the 1950s (Watson, 1981). And there have been sustained efforts to create serious games since 2000 through to present day (Huang, 2019). First, the Quest to Learn program gamifies the entire 6-12 school curriculum (Tekinbas, Torres, Wolozin, Rufo-Tepper, & Shapiro, 2010). Second, *Khan Academy*® has been gamifying mathematics and other educational domains since 2008 (Noer, 2012). Third, *Codecademy*® gamifies computer programming (Kim & Ko, 2017). And finally, Foldit® even gamifies protein folding!

Escape rooms are games which position players as needing to 'escape' from a room by solving a series of puzzles within time limits (Wiemker, Elumir, & Clare, 2015). Originating in Japan in 2007 (Corkill, 2009), they have become a worldwide phenomenon which has even been identified as a source of international tourism (Kolar, 2017). They are starting to be used in an increasing number of academic disciplines including healthcare, e.g. pharmacy (Eukel, Frenzel, & Cernusca, 2017) and nursing (Gómez-Urquiza et al., 2019) and STEM e.g. physics (Vörös & Sárközi, 2017) and computer science (Borrego, Fernández, Blanes, & Robles, 2017). And a convenient design framework (escapeED), has been created to help create educational escape rooms for higher education (Clarke et al., 2017) without a PhD in game design.

The organisation of this paper is as follows. First, we analysed our trial digital electronics escape room with staff players using the escapeED framework. Second, we defined our requirements for our escape room with student players and subsequently designed an escape room to meet these requirements. In this paper we hoped to show that students who participate in an exam revision escape room outperform those students who do not participate. Consequently, we compare exam performance with and without escape rooms.

Analysis using the escapED framework

	Component	Comments
Participants	User Type	A number of player types have been identified (Hamari & Tuunanen, 2014) but we do not consider such types.
	Time	By running multiple iterations, we can determine a reasonable upper bound on time for solving puzzles.
	Difficulty	The puzzles needed to have the same level of difficulty as typical exam questions in digital electronics.
	Mode	Team-based. The puzzles needed to have enough pieces in parallel for teams to work in parallel to compete.
	Scale	We decided to trial teams of 2-5 staff.
Objectives	Learning	We decided to reinforce learning in two areas with room to improve exam performance: bit bashing and waveform decoding.
	Solo/ Multidisciplinary	Undergraduate digital electronics (therefore solo).
	Soft skills	The escape room activity is certainly compatible with Engineer's Australia's stage 1 competency standard for professional engineers, which refers to effective oral communication (3.2) and effective team membership (3.6) (Australia, 2011).
	Problem Solving	We created two puzzles related to our learning objectives.
Theme	Escape Mode	It is unnecessary to create and setup an actual room, there are many versions of online and board game escape rooms.
	Mystery Mode	The puzzles result in a demonstration of digital electronics competency which is not particularly mysterious.
	Narrative Design	While it was fun and creative to design a game narrative, we did not test whether it made any difference to players doing the escape room without the narrative. We chose not to hide any clues in our narrative.
	Standalone / Nested	Our trial escape room was a played at a staff retreat, we hoped that as exam revision the game was a one-off for students.
Puzzles	Design	We based our puzzles on typical exam questions.
	Reflex Learning Objectives	These puzzles were closely linked with the learning goals.
	Instruction / Manuals	The preceding months of lectures, tutorials, practicals, laboratories, and assignments had prepared students.
	Clues / Hints	We wanted to give students hints after a predefined time period, providing a means for teams to narrow down several competing approaches to solutions.
Equipment	Location / Space Design	Given our team design, all that was required per team was a table, sufficient chairs, and sufficient space between teams.
	Physical Props	Each of our puzzles was simply printed out on paper and given to players in a separate sealed envelope, which they were allowed to open on completion of the current puzzle.

	Technical Props	We designed an escape room decoder box into which we programmed the length of time to reveal clues and the correct answer keys (see below).
	Actors	We used no actors in our escape room.
Evaluation	Testing	Our escape room was piloted with a group of seventeen faculty staff members from the School of Engineering and Mathematical Sciences at La Trobe University, from disciplines including electronic, mechanical and civil engineering. Each table had one experienced electronic engineer.
	Reflection	We made many observations but only include three: • On average the fastest team solved the puzzles in half the time of the slowest team. Was this Zipf's law at work? • One team cleverly narrowed the search space by solving 3 out of 4 of the digits then guesses up to ten digits for the final digit. • A post-escape room group of staff recommended that moving players between teams might address potential issues that could adversely impact undergraduate students.
	Evaluate learning objectives	While solving the escape room puzzles demonstrated technical competencies within teams, they do not necessarily demonstrate individual technical competency.
	Adjust	The questions were clarified, and the solution paths simplified for puzzles. One senior staff member did not believe that students would have the technical competency to solve these puzzles and was surprised that the puzzles were based on previous exam questions.
	Reset	With our low-tech setup we could simply reprint or return the paper puzzles to their envelopes and turn off the decoder boxes and we were all ready to go next time the course was run.

In order to run our escape rooms, we designed an open source escape room decoder (Figure 1) which we have made freely available at (Ross R. , 2019a) and further described in (Ross R. , 2019b).

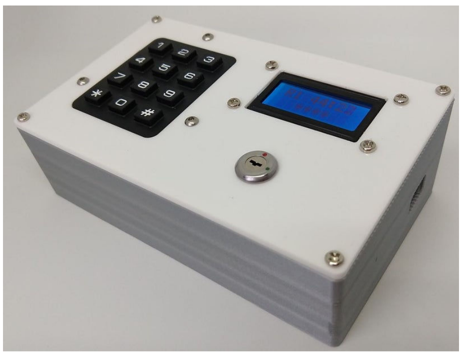

Figure 1: Escape Room Decoder Box

Its onboard Arduino Microcontroller allows a programmer to configure three puzzles with keys consisting of digits of length 1-8. A countdown timer can be configured, as can the timing around clue delivery. Each team has their own box, so they can proceed through the puzzles at their own pace, though they are very aware of the progress of other teams based on the sound effects playing through the box. We have assembled 10 boxes at $30AUD each.

Requirements

We had two main requirements: to improve the exam performance of digital electronics undergraduate students by creating appropriate puzzles for two exam question areas.

In order to benchmark our first requirement, we firstly establish a baseline for performance using the Digital Electronics 2nd year undergraduate exam, which was undertaken by 26 students in 2016.

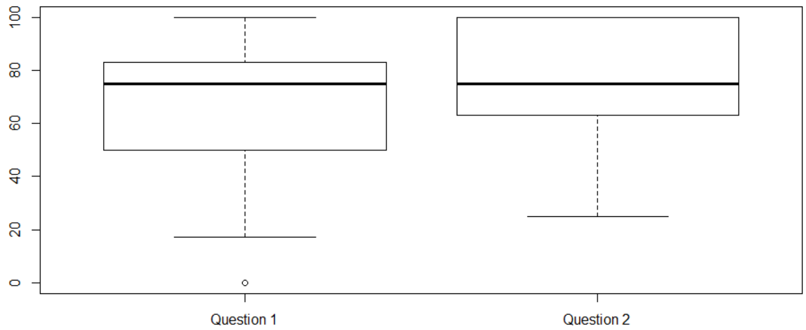

Figure 2: Boxplot Distribution of Bit Bashing Marks for two questions (Q1 and Q2)

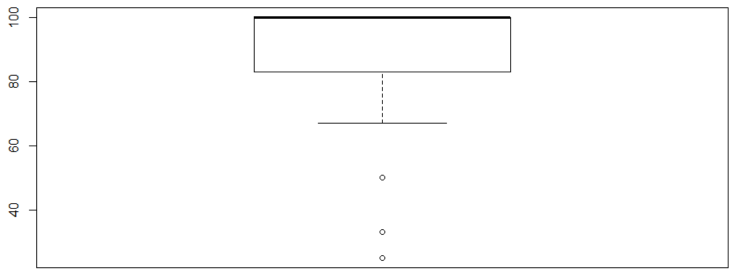

Figure 3: Boxplot Distribution of Waveform Marks

In terms of correlation with overall exam marks, Q1 has r = 0.55, Q2 has r = 0.83 (Figure 2) and for the Waveform question (Figure 3) r=0.59. Of these three questions, Q2 was the best predictor of overall exam performance, with a 95% confidence interval from 0.66 to 0.92.

The second requirement was to create a puzzle based around these questions. The escape room decoder box design constrained our answers to digits, and we decided to continue to use four-digit keys based on our experience with staff. In the bit bashing area, participants required some understanding of programming arithmetic and logical operations (+,-,*,\,%) which were each used to generate the keys.

We also wanted to stay true to the spirit of an escape room game, by keeping the clues coming at a speed that would allow teams to catch up, to some extent, but also so that players would not get stuck on a single puzzle until time ran out. Failure to complete a puzzle would obviously indicate that all members of a team were lacking in technical competency in that area, and we did not wish to cause social embarrassment to teams of students unable to proceed.

Design

For our escape room we created a narrative and two puzzles. At the start of the exam revision activity students opened the first envelope and read out the narrative in their group. It provides a small imaginative relief, with an immersive element, rooted in pop culture and also gave an overview of the objective of players (Figure 4).

> You, and a bunch of other mech droids, were stolen from the big metal mine on the Northern edge of the Jundland Wastes on Tattoine. You are currently in transit to Mos Espa, where you have been told that you will be put to work fixing Podracers, and if that means supplying a few spare parts, well, so be it. Your holding cell is fitted with release keypads, from experience you know that 3 correct combinations (of 4 keys), entered in the right order, will eject you out onto the desert; get it wrong and you'll be Bantha fodder. You're not the first lot of mechs in here, you notice three lots of micro-engraving cut by laser into the wall near the keypad. Can you use the Force and work together with your fellow droids to escape?

Figure 4: Escape Room Narrative (Apologies to George Lucas)

For the Bit Bashing puzzle, players apply an operator to a predefined byte then use an ASCII table to read the character equivalent (Figure 5). The code output is: **Digit 1 is ONE**

```
unsigned char number_1 = 78;    unsigned char number_2 = 156;
unsigned char number_3 = 240;
unsigned char digit[4];

number_1++;    number_2>>=1;    number_3+=85;

digit[0]=number_1;    digit[1]=number_2;    digit[2]=number_3;
printf("Digit 1 is %c%c%c\n",digit[0],digit[1],digit[2]);
```

Figure 5: Bit Bashing Puzzle – Key 1 of 4

For the Waveform puzzle, players needed to read two digits from pairs of waveforms (Figure 6). The example below reads as is 84, which converts to a T in an ASCII table (the key was **TWO**).

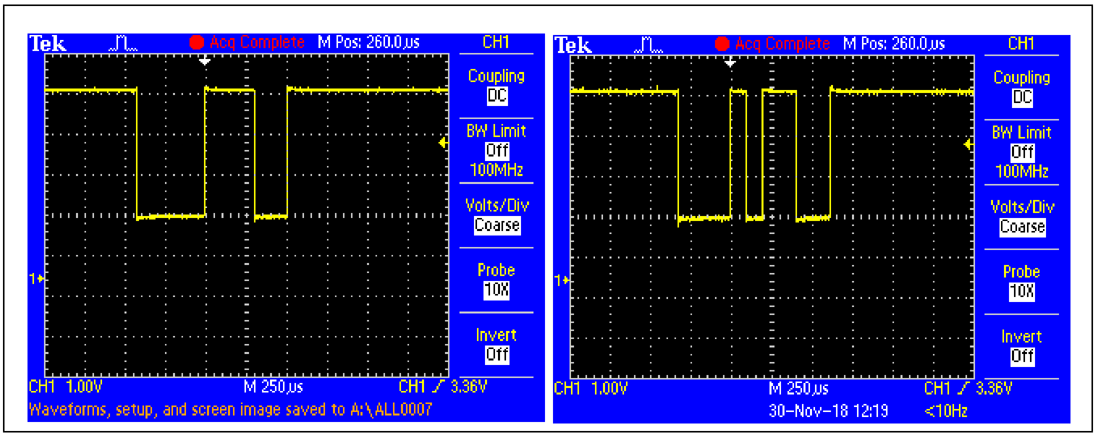

Figure 6: Waveform reading puzzle – Key 1 Letter 1

Evaluation

The Digital Electronics 2nd year undergraduate exam was undertaken by 19 students in 2019. Of these 19 students, 5 students chose not to attend the exam revision escape room, which allows us to compare performance within the 2019 as well as comparing the 2019 with 2016.

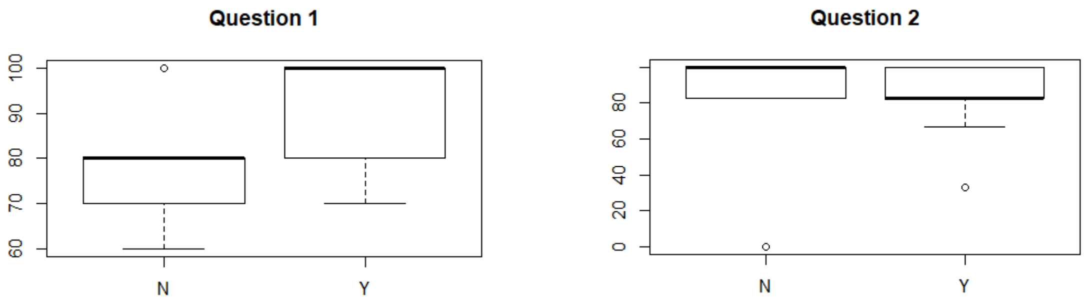

Figure 7: Boxplot Distribution of Bit Bashing Marks. Y means participated in the escape room.

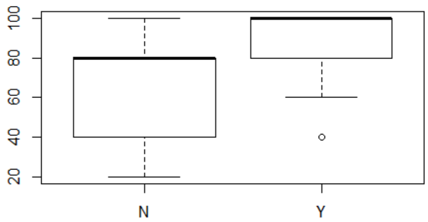

Figure 8: Boxplot Distribution of Waveform Marks. Y means participated in the escape room

These results do not conclusively show that students who played the exam revision escape room in digital electronics (14) outperformed students who did not play (5) (Figure 7). The Bit Bashing boxplot for Question 2 shows the exact opposite (although the students did all perform relatively well on this question in 2019). Nevertheless, Question 1 shows a performance improvement on the 2016 exam, and Question 3 shows a comparable result for those who participated in the escape room between the 2019 and the 2016 exam. These marks weakly correlated with overall exam performance, but should be further clarified with larger sample sizes.
The feedback from the students (held in surveys and focus groups) was overwhelmingly positive. Many students requested additional escape room exercises and many noted on the end of semester feedback survey that the escape rooms were one of their favourite parts of

the subject and they would love to see them across other subjects. One academic commented on observing students in the escape-room that he had “never seen students so focused except in the exam – which they seem to enjoy a whole lot less”.

Conclusion

In this paper we described the application of an escape room game to exam revision in the context of digital electronics. While the results did not demonstrate a significant statistical effect due to sample size, there was a major improvement on the responses to one exam question. These results suggest that escape room puzzles may not be universally effective in exam revision, but that they can yield real performance improvements in some areas of study and are worthy of further exploration. In the near term we are planning to deploy our escape rooms in much larger classrooms, across a wide variety of STEM subjects. Student feedback relating to how engaged they were by the activity was very positive.

There were several unexpected outcomes. First, some students requested that the escape room should be made an assessable part of the subject and were quite specific about how they felt marks should be allocated (approximately 5% per activity). Second, students often seemed to be surprised by their own capacity to solve the escape room puzzles. Finally, the range of times required to solve the puzzles had a surprisingly small standard deviation compared to staff.

References

Ames, C., & Archer, J. J. J. o. e. p. (1988). Achievement goals in the classroom: Students' learning strategies and motivation processes. *80*(3), 260.

Australia, Engineers. J. E. A. (2011). Stage 1 competency standard for professional engineer. 1-6.

Borrego, C., Fernández, C., Blanes, I., & Robles, S. J. J. (2017). Room escape at class: Escape games activities to facilitate the motivation and learning in computer science. *7*(2), 162-171.

Clarke, S., Peel, D. J., Arnab, S., Morini, L., Keegan, H., & Wood, O. J. I. J. o. S. G. (2017). escapED: a framework for creating educational escape rooms and Interactive Games For Higher/Further Education. *4*(3), 73-86.

Corkill, E. J. T. J. T. (2009). Real Escape Game brings its creator’s wonderment to life.

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). *From game design elements to gamefulness: defining gamification.* Paper presented at the Proceedings of the 15th international academic MindTrek conference: Envisioning future media environments.

Eukel, H. N., Frenzel, J. E., & Cernusca, D. J. A. j. o. p. e. (2017). Educational Gaming for Pharmacy Students–Design and Evaluation of a Diabetes-themed Escape Room. *81*(7), 6265.

Gómez-Urquiza, J. L., Gómez-Salgado, J., Albendín-García, L., Correa-Rodríguez, M., González-Jiménez, E., & Cañadas-De la Fuente, G. A. J. N. e. t. (2019). The impact on nursing students' opinions and motivation of using a “Nursing Escape Room” as a teaching game: A descriptive study. *72*, 73-76.

Halter, E. (2006). *From Sun Tzu to xbox: War and video games*: Thunder's Mouth Press.

Hamari, J., & Tuunanen, J. (2014). Player types: A meta-synthesis.

Kim, A. S., & Ko, A. J. (2017). *A pedagogical analysis of online coding tutorials.* Paper presented at the Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education.

Kolar, T. J. I. J. o. C. H. M. (2017). Conceptualising tourist experiences with new attractions: the case of escape rooms. *29*(5), 1322-1339.

Noer, M. J. F. (2012). One man, one computer, 10 million students: How Khan Academy is reinventing education.

Parsons, D. J. I. J. o. E. E. (2008). Is there an alternative to exams? Examination stress in engineering courses. *24*(6), 1111-1118.

Richey, J. E., Nokes-Malach, T. J., & Wallace, A. (2014). *Achievement goals, observed behaviors, and performance: Testing a mediation model in a college classroom.* Paper presented at the Proceedings of the Annual Meeting of the Cognitive Science Society.

Huang, Y. M. (2019). Exploring students' acceptance of educational computer games from the perspective of learning strategy. *Australasian Journal of Educational Technology*, 132-149.

Ross, R. (2019a). *Escape Room Decoder Box*. Retrieved from Instructables: https://www.instructables.com/id/Escape-Room-Decoder-Box/

Ross, R. (2019b). Design of an Open-Source Decoder for Educational Escape Rooms. (IEEE, Ed.) *IEEE ACCESS*, 1-7. doi:10.1109/ACCESS.2019.2945289

Tekinbas, K. S., Torres, R., Wolozin, L., Rufo-Tepper, R., & Shapiro, A. (2010). *Quest to learn: Developing the school for digital kids*: MIT Press.

Vörös, A. I. V., & Sárközi, Z. (2017). *Physics escape room as an educational tool.* Paper presented at the AIP Conference Proceedings.

Watson, H. J. (1981). *Computer simulation in business*: John Wiley & Sons, Inc.

Wellington, P., Thomas, I., Powell, I., & Clarke, B. J. I. J. o. E. E. (2002). Authentic assessment applied to engineering and business undergraduate consulting teams. *18*(2), 168-179.

Wiemker, M., Elumir, E., & Clare, A. J. G. B. L. (2015). Escape room games. *55*.

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