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An escape-room inspired game for genetics review

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ABSTRACT

Active learning strategies engage students in instruction by making them an integral part of the teaching process. Gamification is one type of active learning approach that incentivises student participation by incorporating gaming elements into the learning experience. Although gamification might be an effective strategy for the introduction of new material, adding gaming elements to a review activity can motivate students to study, help them organise material, and identify material that they should review further before an exam. Escape rooms are collaborative problem-solving challenges and aspects of escape-room experiences can be applied to active learning. Here, we describe an escape room inspired review game for an advanced genetic analysis class at Northwestern University. We provide a detailed account of each puzzle within the review game and assess the impact of the game on learning outcomes.

KEYWORDS
Escape room; genetic analysis; active learning; learning-centred teaching

Introduction

Students comprehend and remember material most effectively when they are engaged in the learning process. Learner-centred approaches to teaching involve the use of active, cooperative, and problem-based learning techniques (Prince 2004). Many studies have identified positive effects of learning-centred instruction as opposed to traditional teaching-based lectures, especially in science, technology, engineering, and maths (STEM) disciplines (Ruiz-Primo et al. 2011; Springer, Stanne, and Donovan 1999; Freeman et al. 2014; Prince 2004; Smith et al. 2005; Udovic et al. 2002). These learning-centred approaches offer students a chance to apply critical thinking skills to understand the applications of a lesson at a greater depth.

Gamification, or the use of gaming elements in non-gaming contexts (Deterding et al. 2011), is an increasingly popular method for implementing active learning in the classroom. Although the use of gamification to improve learning outcomes has mixed results, proper implementation of game-based learning can increase student engagement and motivation (van Roy and Zaman 2017; Dichev and Dicheva 2017; Landers 2014; de Sousa Borges et al. 2014). Therefore, the combined use of active learning and gamification strategies to review concepts covered in a course, as opposed to introduce new concepts, can incentivise studying, help students organise material, and assist students in evaluating their depth of knowledge (Gibson 1991; Bord 2008). The challenge for educators is to determine a game format that works for their students and for the material taught in the course.

Escape rooms are interactive experiences that challenge participants to use critical thinking and cooperation to achieve a goal (Nicholson 2015). Although many escape rooms are recreational, the use of escape-room inspired experiences for education has rapidly grown, especially in medical

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education (Kinio et al. 2019; Gómez-Urquiza et al. 2019; Cain 2019; Morrell and Ball 2019; Richelle Monaghan and Nicholson 2017; Dietrich 2018; Adams et al. 2018; Eukel, Frenzel, and Cernusca 2017). Students report that the escape room games in the classroom improved their motivation to study (Kinio et al. 2019; Gómez-Urquiza et al. 2019; Dietrich 2018), helped them conceptualise and retain curriculum (Gómez-Urquiza et al. 2019; Morrell and Ball 2019; Kinio et al. 2019; Eukel, Frenzel, and Cernusca 2017), revealed topics they should spend more time reviewing (Morrell and Ball 2019), and were overall enjoyable experiences (Kinio et al. 2019; Gómez-Urquiza et al. 2019; Morrell and Ball 2019; Cain 2019; Dietrich 2018; Adams et al. 2018; Richelle Monaghan and Nicholson 2017). The hands-on challenges and time sensitivity of an escape room has obvious parallels to some of the practical skills needed for medical professions. Therefore, the use of escape rooms in medical education seems to be a clear fit. However, escape rooms might not be limited in this capacity. Indeed, they might be effective as review games for a wide array of subjects outside of the medical field.

Here, we present the design and implementation of an escape room game for BIOL_SCI 393: Genetic Analysis at Northwestern University. This activity supplemented study guides and review sessions for the final exam. During the game, students collaborated to solve genetic puzzles, ultimately unlocking the 'Nobel Prize'. Each puzzle in the game covered a core concept that was taught in the course and would appear on the final exam. We discuss the workflow of the game, assess student responses, and offer suggestions for designing future escape room review activities.

Methodology

Participants

Students enrolled in BIOL_SCI 393, Genetic Analysis, were offered the option to participate in the escape room exam review session. Eighteen students were enrolled in the course (15 seniors and three graduate students) and nine students (eight seniors and one graduate student) participated in the escape room activity.

Location and set up

The escape room review session took place in a standard lecture room on campus. Students were split into two groups (one group of five students and another group of four students) to offer each student a more active role in the game. The teaching assistant acted as the facilitator for the activity and delivered clues when appropriate but did not offer solutions to challenges in the room.

Each activity was placed in a wooden box with some form of lock, and the boxes were placed throughout the room (Appendix A). When the students entered the game room, they noticed six locked boxes (Appendix A), a list of tools for a mutagenesis screen written on the whiteboard (Appendix A), a whiteboard drawing labelled 'GFP plasmid' (Appendix A, Appendix B), a whiteboard drawing of a cell lineage (Appendix A, Appendix B), and a mysterious poster board with hooks and elastic ID badge holders (Appendix A, Appendix B).

Assessment of impact

At the end of the class period three days before the escape room activity, the instructor handed each student (whether participating in the escape room or not) a pre-escape room survey (Appendix C). The pre-escape room survey contained 16 Likert-scale questions that gauged student confidence about understanding course material and three on-topic problems, similar to exam questions. Students were given ample time to complete the survey. Immediately after the escape room was completed and the facilitator discussed the concepts and answered questions, participants were given the post-escape room survey (Appendix D). The post-escape room survey contained all questions from the pre-escape room survey as well as ten Likert-scale questions regarding the impact of the escape room and two open-response questions.

Analysis of results

To de-identify the surveys, students selected a four-digit code to write at the top of the pre- and post-escape room surveys. Wilcoxon matched-pairs signed-ranks tests were used to compare pre- and post-escape room survey responses. *P*-values less than 0.05 were deemed significant. All statistical tests were calculated using R (Core Team, R. n.d.).

Escape room workflow

Before the escape room review game took place, the facilitator printed all prompts (Appendix E), tested all puzzles and locks (Appendix B), and set up the room according to the planned layout (Figure 1). The facilitator followed the workflow in Appendix F to ensure the game was consistent across groups. A summary of the escape room workflow is described below.

Introduction

After all students had entered the room, they were presented with the **Introductory Prompt** (Appendix E): 'Congratulations! You have won the Nobel Prize for your work in *Photinus pyralis*, which, as you obviously know, is the scientific name for the Big Dipper Firefly. You performed flawless genetic experiments, identified several genes involved in the bioluminescence of this wonderful organism, and found genetic tests for diseases in the species, eventually earning you the highest honour in the field. However, your jealous lab mate doubts your knowledge of genetics and has hidden your Nobel Prize in this room. To prove that you have earned this award and claim

Figure 1. Escape room setup. Boxes were scattered throughout the classroom, and particular clues were written on the board, as detailed in Appendix A.

what is rightfully yours, you must complete a series of tasks, unlock several boxes, and find your Nobel Prize before you give your big acceptance speech in one hour! Good luck!'

Step 1: mutagenesis

The facilitator handed **Prompt 1** (Appendix E) to the students and started the timer that would expire after one hour. The prompt indicated that the students needed to draw a mutagenesis screen on the board (Appendix B).

Step 2: complementation

When the mutagenesis screen was correct, the facilitator handed **Key 1** (Appendix A) to the students, which they used to unlock **Box 1** (Appendix A). Inside, they found **Prompt 2** (Appendix E), and a set of tea lights that were each labelled with a combination of two mutations (Appendix B). The students tested the ability of each combination of mutants to glow by turning on each tea light and used this information to identify the largest non-complementation group (Appendix B). The numeric identifiers of the mutants in the largest non-complementation group were used to unlock **Box 2** (Appendix A) once they were arranged according to the clue on the lock (Appendix B).

Step 3: epistasis

Inside **Box 2** (Appendix A), the students found **Prompt 3** (Appendix E) and the **Epistasis Circuit** (Appendix B). The students flipped the switches on the circuit board on and off to understand how the presence or absence of certain gene products affected the output of the phenotype (the colour of the light). Using this information, the students organised the biosynthetic pathway of these modelled genes and identified the most upstream gene in the pathway (Appendix B). This gene name was used to unlock **Box 3** (Appendix A).

Step 4: designing plasmids

In **Box 3** (Appendix A), the students found **Prompt 4** (Appendix E), magnets labelled with promoter types and alleles of genes (Appendix B), and a black light. The students placed the magnets into the **Expression Plasmid** on the blackboard (Appendix A, Appendix B). When they selected the correct magnets (Appendix B), the facilitator handed them **Gene Expression Poster** (Appendix B).

Step 5: nascent expression

The students used the black light to look for expression of the gene product on the **Gene Expression Poster**, which shows a firefly drawing. Once they correctly identified the cells that were fluorescing (Appendix B), the facilitator handed them **Prompt 5** (Appendix E).

Step 6: designing experiments

The students selected the experimental tools they would need to test whether the gene function was required in certain cells. When they selected the correct combination of tools (Appendix F), the facilitator handed them **Prompt 6** (Appendix E), the **Mutant Firefly Box** (Appendix B) and three iron nails (Appendix B).

Step 7: cell autonomy

Following **Prompt 6**, students plugged the three nails, each representing a wild-type allele of *dim1* into the given holes on the **Mutant Firefly Box**. When they did not see the box light up, they told the facilitator what this means about the cell autonomy of the gene product (Appendix F). When their answer was correct (Appendix F), the facilitator handed them **Prompt 7** (Appendix E).

Step 8: rescue and ablation

Combining the information on **Prompt 7** (Appendix E), the **Cell Lineage** drawn on the blackboard (Appendix A, Appendix B), and information from Steps 6 and 7, the students deduced where the function of the gene product is required to make the animal light up. They then placed the three iron nails into the corresponding slots in the **Mutant Firefly Box** (Appendix B). When correct, the **Mutant Firefly Box** lit up and displayed the code to unlock **Box 4** (Appendix B).

Step 9: time of activity

In **Box 4**, the students found **Prompt 8** (Appendix E) and six **Time of Gene Action** envelopes labelled '0', '2', '4', "6", "8" and '10' that each contained glow sticks (Appendix A, Appendix B). The students tested the glow sticks for the number of 'animals' in the population that had the wild-type glowing phenotype. If the students did not know how to use glow sticks, the facilitator instructed them to crack them. The students then stated the developmental times in which the gene function was required. If correct (Appendix B), the facilitator handed them the **Modes of Inheritance Pedigrees** (Appendix B) and **Prompt 9** (Appendix E).

Step 10: modes of inheritance

The students determined the mode of inheritance for each of the **Modes of Inheritance Pedigrees**. They then matched each pedigree to its proper mode of inheritance on the **Mysterious Poster Board** by stretching the ID tags from top hooks to bottom hooks. When correct, the strings from the ID tags made a pattern that crossed over three numbers on the **Mysterious Poster Board** (Appendix B). These three numbers were used to unlock **Box 5** (Appendix A).

Step 11: informative individuals

In **Box 5** (Appendix A), the students found **Prompt 10** (Appendix E) and four **Triplet Pedigrees** (Appendix B). When the students correctly selected the most informative triplet for a linkage mapping experiment (Appendix B), the facilitator handed them a **Linkage Pedigree** derived from the F1 individual of the selected triplet (Appendix B). The students determined the number of recombinant progeny in the pedigree and calculated the LOD score of the linkage between the disease and the marker loci using a theta score indicated on the **Linkage Pedigree** (Appendix B). The correct LOD score unlocked **Box 6** (Appendix A).

Step 12: GWAS

Inside **Box 6** (Appendix A), the students found **Prompt 11** (Appendix E), and a collection of **GWAS Pipe Cleaners**, folded into shapes (circles or straight lines) that represented the flight patterns of mutant fireflies. Each 'flight pattern' was labelled with alleles at three potentially correlated SNPs (Appendix B). Students identified the SNP most highly correlated with the mutant (circular) flight path (Appendix B). Then, they used the genetic sequence of the triplet containing the correlated SNP with the putative disease allele (Appendix B) to unlock **Box 7** (Appendix A).

Step 13: receive nobel prize

Inside **Box 7** (Appendix A), the students found a replica of the Nobel Prize. The timer was stopped to record the amount of time needed to complete the escape room activity.

Step 14: debriefing

After each group completed the escape room, the facilitator walked through each of the activities briefly to highlight the topics that were reviewed and the correct answers. At this time, the facilitator answered questions regarding how the escape room activities modelled the concepts covered in the class. If a group did not complete the room in time, the facilitator would walk through the missed concepts with the group to guide them through the complete experience. After the debriefing session, each student was given the post-escape room survey (Appendix D).

Results

Both of the groups completed the experience in less than one hour. The first group (with five members) completed the escape room in about 40 minutes, and the second group (with four members) completed in about 45 minutes. All students who participated in the escape room filled out pre- and post-escape room surveys (Appendix C, Appendix D), and some students who did not participate in the escape room filled out a pre-escape room survey (Appendix C).

To determine if escape room participation was correlated with student confidence about exam material, we compared the pre-escape room survey responses for students who either did or did not participate in the escape room. Of the sixteen Likert-scale questions on the surveys, one question did show significantly different responses between students who chose to participate versus students who opted out of the activity. Students who chose to participate in the escape room were less confident when responding to the pre-escape room survey statement 'I can follow the steps of genetic analysis from beginning to end' than their peers who opted out of the experience (Figure 2, *p*-value = 0.038, Wilcoxon test). After the escape room, the responses of students who participated in the escape room were not significantly different than the pre-escape room responses of their non-participatory peers (Figure 2, *p*-value = 0.180, Wilcoxon test). Therefore, the escape room might have improved students' understanding of genetic analysis as a process, not just as discrete topics.

To assess the impact of the escape room, we compared pre- and post-escape room survey responses from students who chose to participate in the activity. We performed a Wilcoxon matched-pairs signed-ranks test to identify any significant increases or decreases in student confidence in comprehension of course material covered in the escape-room experience (Figure 3). Five questions showed significant differences between the pre- and post-escape room responses, and each of these significant changes displayed increases in confidence after the activity. One of these five questions was question 14, as discussed above. The other four questions with significant improvements were related to particular topics that were reviewed during the escape room: 'I can identify where a gene is naturally expressed,' 'I can assess cell autonomy of a gene product,' 'I can use ablation results to see where a gene's function is necessary,' and 'I can assess the developmental time of a gene's action.' Although this improved confidence could be attributed to the escape room, we cannot rule out the effects of other studying strategies that were used by participants between pre- and post-survey administration.

In addition to the Likert-scale questions, the pre- and post-escape room surveys contained questions that tested student comprehension of key concepts: complementation, epistasis, and cell autonomy. Before the escape room, 100%, 67%, and 67% of students who chose to participate in the escape room wrote the correct answer to the complementation, epistasis, and cell autonomy content questions, respectively. After the escape room, 100%, 100%, and 78% of students wrote the correct response to the same complementation, epistasis, and cell autonomy content questions,

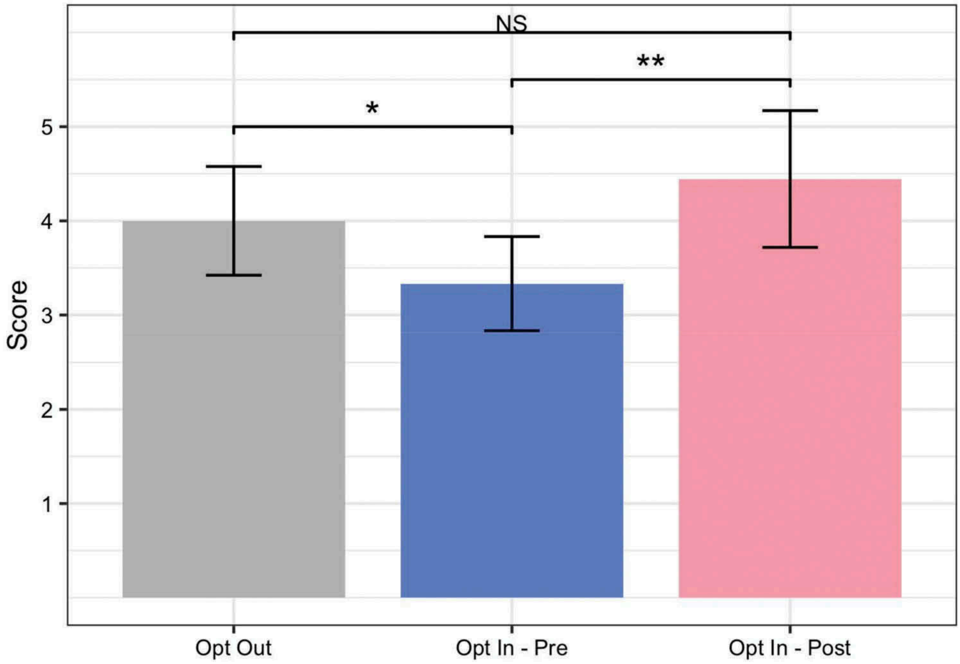

Figure 2. Responses to question 14: 'I can follow the steps of genetic analysis from beginning to end,' are shown. On the y-axis, the mean Likert-scale score for the survey question is shown, split into groups of students who opted out of the escape room (grey $n = 7$), pre-escape room survey of students who opted in (blue, $n = 9$), and post-escape room survey of students who opted in (pink, $n = 9$). Each bar shows the mean score among the population, and the error bars show the standard deviation. Significance of p-values between groups are reported at the top (NS = 0.180, * = 0.038, ** = 0.019; Wilcoxon test).

respectively. Therefore, student comprehension of certain topics might have improved because of the escape room. However, we cannot necessarily attribute this increase in comprehension to the escape room activity rather than other exam preparation strategies that participants used between pre- and post- survey administration. For these three topics, we tested for correlation between student confidence, measured by the 'I can … ' statements from the survey, and comprehension-question results. We did not find any statistically significant correlations between confidence and comprehension (point biserial correlation, p-values > 0.05). However, larger sample sizes are needed to definitively test the relationship between confidence and comprehension.

We also used the post-escape room survey to gauge how effective and enjoyable the experience was for the students (Figure 4). Each of these ten Likert-scale questions received favourable scores of mostly fours (4 = agree) and fives (5 = strongly agree). No students gave scores of one (1 = strongly disagree) or two (2 = disagree) for any of these questions. Overall, the students found the escape room to be an enjoyable experience and a helpful review strategy for the final exam.

The two open-response questions on the post-escape room survey captured several themes of the student experience. The most apparent theme highlighted in these responses was that the escape room activity was enjoyable. Students wrote comments such as 'It was fun and creative!' and 'I thought it was a very fun and helpful activity.' In addition to the enjoyment, students commented on specific course concepts that were clarified during the experience: 'I learned more about the logic of GWAS,' 'I practiced a mutagenesis screen, which as been the hardest topic for me in the class,' and 'I think I understand cell autonomy/ablation experiments better.' Participants also mentioned that the escape room allowed them to see how the course material fits into the larger process of genetic analysis: 'I enjoyed putting all the pieces together in one sitting. It helped me see the bigger picture.' Finally, students stated that the escape room helped them practice some skills that are translatable to other classes or experiences, such as teamwork and efficient problem solving.

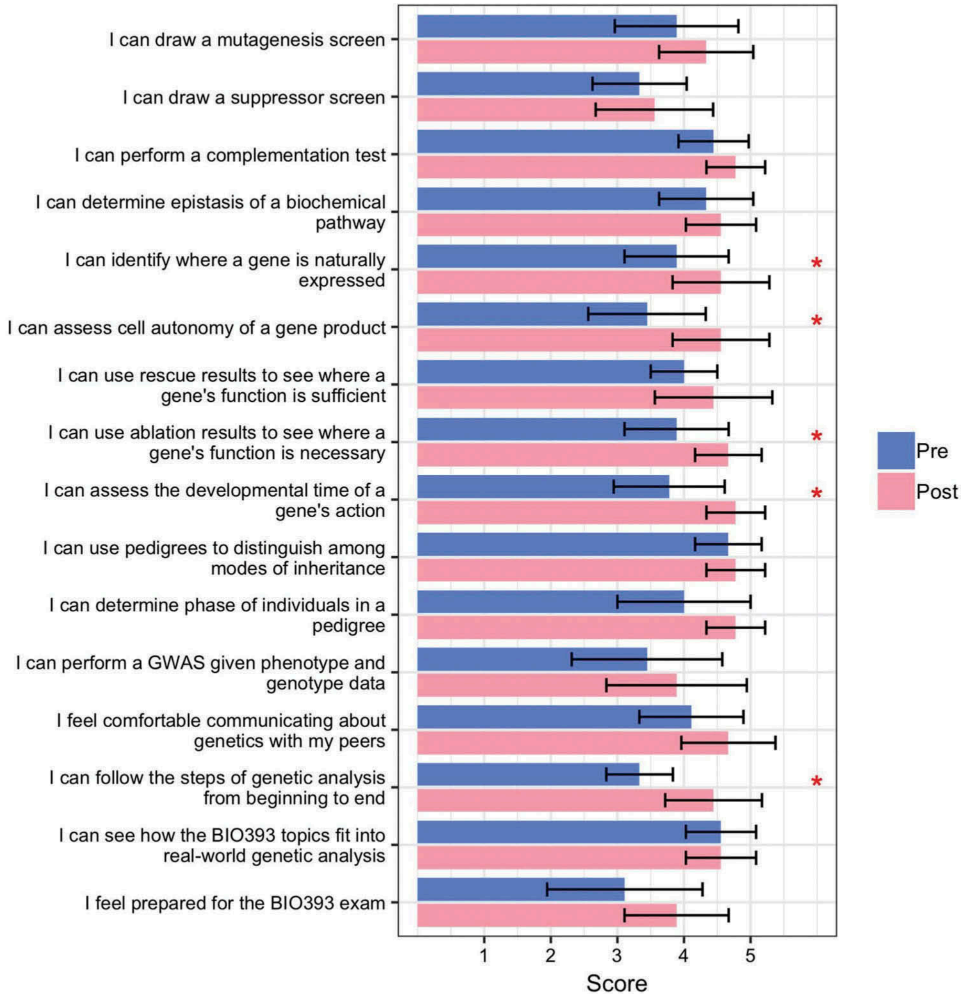

Figure 3. Comparisons of pre-escape room and post-escape room survey results are shown. On the y-axis, each of the 16 Likert-scale questions from the surveys are written. Each bar shows the mean score along the x-axis, coloured by pre- (blue) or post- (pink) surveys. Error bars show standard deviations around each mean. Questions with significant differences between pre- and post- scores are indicated by a red asterisk (p-value < 0.05, Wilcoxon paired-sample rank-sum test).

Impact and applications

Comparisons of pre- and post-survey results suggest that this escape room review game was successful in many ways, such as increasing student engagement, improving retention of the subject matter, and helping students understand how the topics learned in the classroom fit into the process of genetic analysis. However, the effect of outside studying techniques that participants used between pre- and post-survey administration cannot be determined. Nonetheless, students enjoyed the escape room activity and felt that it helped them review concepts before the final exam. However, some aspects of the game can be improved. For example, the experience can be expanded to include more course content, as requested by one participant. Additionally, certain puzzles in the room are fragile, specifically the epistasis circuit and the mutant firefly box. Making more robust prototypes of these puzzles would decrease the amount of test time that is required to set up the room.

The development of this game involved several cycles of design, implementation, evaluation, and editing across the three academic years during which we presented this activity. We attribute the

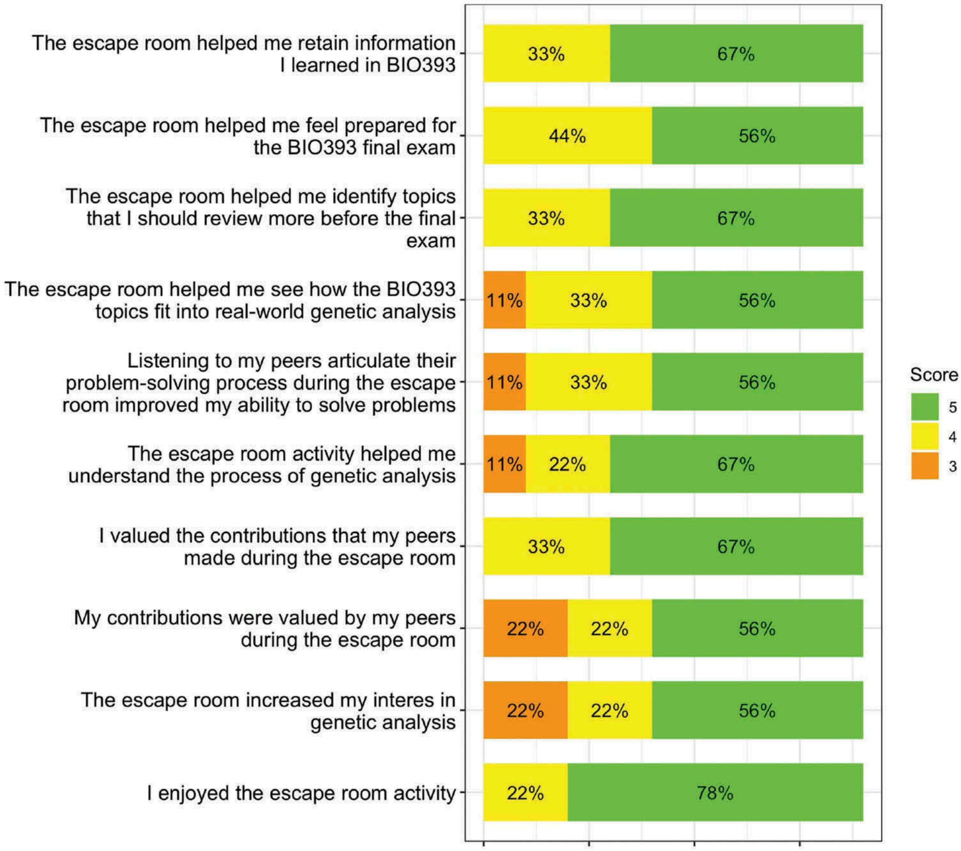

Figure 4. Student feedback regarding the escape room is shown. For each question along the y-axis, the percentage of students that scored three (orange, 3 = neither agree nor disagree), four (yellow, 4 = agree), or five (green, 5 = strongly agree) is shown as a stacked bar plot with written percentages printed for each group. No students gave scores of one (1 = strongly disagree) or two (2 = disagree) for any question, so those scores are not shown.

successes of our escape room to a stepwise process of game design. Below, we offer these steps to assist the design of a similar review game for other courses.

First, we established specific learning objectives that framed the basis of the escape room. For this course, we selected core concepts that would appear on the final exam and sought to review each of those topics during the game. Future educational escape room designers might benefit from similarly establishing the core concepts they aim to cover during the game.

Next, we conceptualised a theme that would remain consistent during the escape room. Theme selection was a challenging piece of the design, because we wanted a theme that would tie all puzzles together and offer variation in the type of puzzle. We selected the theme of firefly genetics, because we imagined a variety of puzzle types that could model aspects of a bioluminescence phenotype (e.g. turning lights on or off, building circuits, assessing variation in light colour). In our escape room game, we intentionally used the theme to create a storyline, because we wanted the students to think of genetics as a process rather than a series of disjointed puzzles. However, the game designer can choose a theme as an overarching concept without creating a storyline for the flow of the game, depending on the goal of the escape room.

After selecting a theme, we chose a layout of game design that would fit our purposes. Because we were using the escape room as an exam review, we wanted all students to be involved in each step of the game. Therefore, we selected a linear path that requires students to solve one puzzle before they gain access to the next puzzle. We considered an alternative layout, where students split into different groups and each group solves an independent track of puzzles in parallel, eventually leading each group to the final challenge that they would complete together. This type of design could be beneficial in other contexts, especially where the escape room is used as a tool to assess individual student aptitude. Of course, a mixture of the linear and parallel layouts could be designed, depending on the goal of the game.

Finally, with our learning objectives, theme, and layout in hand, we began designing puzzles. This part of the game design took the most amount of time, effort, and editing. We first brainstormed types of light-related phenomena that could be used during the game and identified the learning objectives that could be modelled by each of those phenomena. For example, using a blacklight to expose invisible ink could represent fluorescent protein expression, which is invisible unless excited by a light of the proper wavelength. We then researched types of padlocks and brainstormed ways in which solutions to our genetics puzzles could be used to unlock boxes. The cycle of implementation, evaluation, and editing is an ongoing process that continues to improve the design of our escape room.

In conclusion, we designed an escape room game for the BIOL_SCI 393: Genetic Analysis final exam review. We found that this review strategy increased student understanding of how course topics fit together, likely improved comprehension of particular course concepts (although other study strategies might have contributed to this improvement), and was a generally enjoyable experience. The steps we used to design our escape room can be applied to other topics outside of genetics and even outside of STEM. Because learning-centred practices encourage deep understanding of concepts, escape room review activities offer a unique method by which studying for exams can become not only more enjoyable but more effective than traditional exam review sessions.

Educational implications

The escape room activity was a successful strategy for exam review. Not only did students enjoy this alternative method for studying, but they found the experience to be helpful for seeing the bigger picture of the course material. The logical flow of the storyline in our escape room likely helped students experience and understand the process of genetic analysis. Educators who wish to design an escape room for their own course should consider a storyline theme to help students appreciate the logic of stepwise processes. To measure the effect of the storyline component in particular, future studies could compare the impact of a storyline escape room to the impact of individual activities without an overarching narrative. Furthermore, additional survey questions should be designed to define what exactly makes the escape-room review game effective (e.g. narrative, collaboration, time limit).

Because escape rooms are participant-driven by nature, this style of review game allows the facilitator to take a more observational role to the student learning. Not only does this shift encourage students to take an active role in the learning process, but it also allows the facilitator to observe the students' problem solving approaches in real time. During the debriefing session after each run of the escape room, the facilitator can point out mistakes or alternative ways of approaching problems.

Finally, this format of exam review encourages teamwork and collaboration among students. Not only do students have a common goal (to complete the challenge), which instils a sense of camaraderie among participants, but they also work together on complex puzzles. This collaborative activity helps peers learn from hearing each other's thought processes and improves student confidence in communicating about complex topics with peers. In an escape room review game, students work together towards a common goal and are truly at the centre of the learning process.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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References

Adams, V., S. Burger, K. Crawford, and R. Setter. March 2018. "Can You Escape? Creating an Escape Room to Facilitate Active Learning." *Journal for Nurses in Professional Development* 34(02).

Bord, D. 2008. "Enhancing Learning and Exam Preparation." *APS Observer* 21 (1). https://www.psychologicalscience.org/observer/enhancing-learning-and-exam-preparation

Cain, J. 2019. "Exploratory Implementation of a Blended Format Escape Room in a Large Enrollment Pharmacy Management Class." *Currents in Pharmacy Teaching & Learning* 11 (1): 44–50. doi:10.1016/j.cptl.2018.09.010.

Core Team, R. n.d. "R: A Language and Environment for Statistical Computing." R Foundation for Statistical Computing. http://www.R-project.org/

Deterding, S., D. Dixon, R. Khaled, and L. Nacke. 2011. "From Game Design Elements to Gamefulness: Defining 'gamification." In *Proceedings of the 15th International Academic MindTrek Conference*: Envisioning Future Media Environments, 9–15. Tampere, Finland.

de Sousa Borges, S., V. H. S. Durelli, H. M. Reis, and S. Isotani. 2014. "A Systematic Mapping on Gamification Applied to Education." In *Proceedings of the 29th Annual ACM Symposium on Applied Computing*, 216–222. Gyeongju, Republic of Korea, ACM.

Dichev, C., and D. Dicheva. 2017. "Gamifying Education: What Is Known, What Is Believed and What Remains Uncertain: A Critical Review." *International Journal of Educational Technology in Higher Education* 14 (1): 9. doi:10.1186/s41239-017-0042-5.

Dietrich, N. 2018. "Escape Classroom: The Leblanc Process—An Educational 'Escape Game.'." *Journal of Chemical Education* 95 (6): 996–999. doi:10.1021/acs.jchemed.7b00690.

Eukel, H. N., J. E. Frenzel, and D. Cernusca. 2017. "Educational Gaming for Pharmacy Students - Design and Evaluation of a Diabetes-Themed Escape Room." *American Journal of Pharmaceutical Education* 81 (7): 6265. doi:10.5688/ajpe816103.

Freeman, S., S. L. Eddy, M. K. Miles McDonough, N. O. Smith, H. Jordt, and M. P. Wenderoth. 2014. "Active Learning Increases Student Performance in Science, Engineering, and Mathematics." *Proceedings of the National Academy of Sciences of the United States of America* 111 (23): 8410–8415. doi:10.1073/pnas.1319030111.

Gibson, B. 1991. "Research Methods Jeopardy: A Tool for Involving Students and Organizing the Study Session." *Teaching of Psychology* 18 (3): 176–177. doi:10.1207/s15328023top1803_13.

Gómez-Urquiza, J. L., J. Gómez-Salgado, L. Albendín-García, M. Correa-Rodríguez, E. González-Jiménez, and G. A. Cañadas-de la Fuente. 2019. "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): 73–76. doi:10.1016/j.nedt.2018.10.018.

Kinio, A. E., L. Dufresne, T. Brandys, and P. Jetty. 2019. "Break Out of the Classroom: The Use of Escape Rooms as an Alternative Teaching Strategy in Surgical Education." *Journal of Surgical Education* 76 (1): 134–139. doi:10.1016/j.jsurg.2018.06.030.

Landers, R. N. 2014. "Developing a Theory of Gamified Learning: Linking Serious Games and Gamification of Learning." *Simulation & Gaming* 45 (6): 752–768. doi:10.1177/1046878114563660.

Morrell, B. L. M., and H. M. Ball. January 2019. "Can You Escape Nursing School?: Educational Escape Room in Nursing Education." *Nursing Education Perspectives*: 1. doi:10.1097/01.NEP.0000000000000441.

Nicholson, S. 2015. "Peeking behind the Locked Door: A Survey of Escape Room Facilities." http://scottnicholson.com/pubs/erfacwhite.pdf

Prince, M. 2004. "Does Active Learning Work? A Review of the Research." *Journal of Engineering Education* 93 (3): 223–231. doi:10.1002/jee.2004.93.issue-3.

Richelle Monaghan, S., and S. Nicholson. 2017. “Bringing Escape Room Concepts to Pathophysiology Case Studies.” *Journal of the Human Anatomy and Physiology Society* 21 (2). http://scottnicholson.com/pubs/escaperoompatho.pdf

Ruiz-Primo, M., D. B. Araceli, H. Iverson, R. Talbot, and L. A. Shepard. 2011. “Impact of Undergraduate Science Course Innovations on Learning.” *Science* 331 (6022): 1269–1270. doi:10.1126/science.1198976.

Smith, K. A., S. D. Sheppard, D. W. Johnson, and R. T. Johnson. 2005. “Pedagogies of Engagement: Classroom-Based Practices.” *Journal of Engineering Education* 94 (January): 87–101. doi:10.1002/jee.2005.94.issue-1.

Springer, L., M. E. Stanne, and S. S. Donovan. 1999. “Effects of Small-Group Learning on Undergraduates in Science, Mathematics, Engineering, and Technology: A Meta-Analysis.” *Review of Educational Research* 69 (1): 21–51. doi:10.3102/00346543069001021.

Udovic, D., D. Morris, A. Dickman, J. Postlethwait, and P. Wetherwax. 2002. “Workshop Biology: Demonstrating the Effectiveness of Active Learning in an Introductory Biology Course.” *Bioscience* 52 (3): 272–281. doi:10.1641/0006-3568(2002)052[0272:WBDTEO]2.0.CO;2.

van Roy, R., and B. Zaman. 2017. “Why Gamification Fails in Education and How to Make It Successful: Introducing Nine Gamification Heuristics Based on Self-Determination Theory.” *In Serious Games and Edutainment Applications* 2: 485–509.