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A How to Guide and Template for Designing a Puzzle Based Escape Room Game

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Abstract

Educational games are one active and effective way of engaging students with material while also providing additional motivation to tackle challenging concepts. A particularly popular game concept is the escape room, where students need to work in groups to solve a series of puzzles to prevent disaster from occurring in an imaginary universe, all within a specified amount of time. This paper presents a general guide to constructing an escape room for undergraduate classrooms. Unlike many recently published educational escape rooms, this template does not use any laboratory-based components, making it widely applicable to any class and any level, although it will be most easily adapted to classes that do include analytical components. The puzzles in the game escalate from remembering and understanding concepts to applying and evaluating techniques and data. Unlike many other games and puzzles, an escape room does not reveal the final answers until the allocated time is up, which forces students to work through challenging questions and find solutions within their group to advance in the game. The game provides students many instances for formative assessment and encourages helpful discussions surrounding misconceptions and core course content while they escalate through the challenges.

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Supporting Materials: Supporting Files S1. Escape Room Design – Description of Universe and Final Answer Sheet; S2. Escape Room Design – Challenge Round 1: ASN and Find the Floor; S3. Escape Room Design – Challenge Round 2: Color Coded Equation Questions; S4. Escape Room Design – Challenge Round 2: Color Barcode Envelope Map; S5. Escape Room Design – Challenge Round 2: Color Coded Equation Sheet; S6. Escape Room Design – Challenge Round 3: Rank the Options Question; and S7. Escape Room Design – Challenge Round 4: Find the Antidote.

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INTRODUCTION

Active learning techniques have been shown to improve student learning outcomes (1). Educational games have additional benefits beyond those common to active learning such as enhancing problem solving, communication, and cooperation skills (2). Games also help to motivate students struggling to learn abstract concepts by making content more tangible and providing a fun way to interact with these concepts. A newer game format is an escape room. Escape rooms create a scenario where players need to work together to solve a series of increasingly complex puzzles within a specified amount of time (3). The number of publications on escape rooms at both the high school and university levels have dramatically increased in recent years and have shown that this game format successfully promotes understanding of key learning outcomes and positive student experiences (4-7).

However, designing a valuable educational game takes extensive time and planning (8), and few resources exist to help with the fundamental layout of an educational escape room. Most of the published escape room articles apply to physics or chemistry and involve primarily experimental challenges. Many courses, however, do not have laboratory components or have extensive material to teach beyond a lab setting. This template is based on question sets and clues where one solution leads students to find the next challenge. Although the question format in this template is most easily translated to a course that involves some mathematical or graphical analysis (genetics, ecology, etc.), the template is adaptable to any class or material.

PURPOSE OF THE ESCAPE ROOM CHALLENGE

I implemented this game in a sophomore level Biomolecular Thermodynamics course that comes at a hinge point between general science requirements and higher level coursework. I noticed that many of my students struggled to begin solving a problem that they did not immediately understand. During class or office hours, students would get as far as they could before guessing or waiting for the solution to be revealed. Having an openly revealed answer allowed students to avoid thoughtfully engaging in problem solving. When I was selecting a game format, I wanted to push my students to find the final answer as a team, even when they were not sure how to start, or if they got stuck in the middle. I wanted to teach them valuable skills in problem solving, increase their confidence, and help them self-correct their misconceptions. I used the escape room described here as an out-of-class review session. The game could also be used as an in-class review broken over multiple days or modified to include mini lectures to adapt to a problem based learning environment.

GAME SET UP AND LOGISTICS

Escape rooms are typically based on a mystery or problem that must be solved in a time sensitive manner. My escape room was based on a 'zombie apocalypse.' The students were charged with finding the antidote to the zombie virus before it spreads beyond the city borders and destroyed human life as we know it. To do this, they needed to complete four Challenge Rounds to find and determine which antidotes can cure the virus. These Challenge Rounds escalate trough Bloom's Taxonomy, a framework for categorizing educational goals from less cognitively demanding (remembering and understanding) to more demanding (applying, evaluating, and creating; 9).

The template described here is for a 2-2.5 hour escape room with 10 groups of five students. All of the questions in the template provided in the Supporting Files relate to chemical, phase, and mixture equilibrium from a unit in Biomolecular Thermodynamics. Some of the questions provided may be directly applicable in a chemistry, biochemistry, physical chemistry, or molecular biology course but primarily will serve as a template for question ideas. Before beginning to design your own game content, you need to first determine a few key game parameters: time limit, group size, and area of play. Each of these aspects will be important for determining how large your question banks need to be, how many distinct sets of clues you will need, how many rounds of challenges you will need to create, and how many/what type of hiding spots you will be able to use for solutions.

Time Limit

How much time you want to spend playing the game will determine how many questions you should make per Challenge Round. The earlier Challenge Rounds focus on the lower levels of Bloom's taxonomy (remember, understand) and the later challenges focus on the higher levels (apply, analyze, and evaluate). If you need to decrease the amount of time, it is best that you shorten individual rounds so that students are presented with questions of varying difficulty.

Group Size

You should aim to have no more than five students per group to enhance student collaboration, but fewer is likely better for more cohesive group dynamics. I randomly assigned groups so students would meet and work with new people to get exposed to new ways of approaching problems. Another reason for random groups was to increase the problems that normal study groups in the class saw so that they could compare notes while preparing for the exam. Because multiple teams are completing similar tasks in the same physical space (e.g., a classroom), each group needs to receive their own distinct set of questions per Challenge Round. You should create a question bank for each round that you can draw from to create a distinct set of questions for each group. A recommended number of questions for each Challenge Round will be discussed in detail later.

Area of Game Play

Once you have selected your overall room or building area, make a list of places you could hide your clues such as stairs, windows, tables, chairs, rooms, etc. If you are in a single room, you could have players tell you a code to get their next clue without having them find it or set up a matrix of envelopes where a solution will indicate which envelope provides the next set of questions (here used for Challenge Round 2 with a template provided in Supporting File S4. Escape Room Design – Challenge Round 2: Color Barcode Envelope Map). The answers for Challenge Round 1 assume a whole building area and would need to be modified if you had a smaller area.

GAME DESIGN AND PLAY

Once you have determined the length and space for your game, you can dive into creating content! For clarity, an overview of game play is shown in Figure 1. The solution to each Challenge Round will provide students with the information leading them to the hidden location of the question(s) for the next round. To begin the game, you should divide students into groups and then explain the virtual game universe (zombie apocalypse), their challenge (find an antidote), how they will get there (solving the challenges), and how much time they have to finish (time limit). Once you have explained the game, you will provide each group the description of the game universe and the final answer template (Supporting File S1. Escape Room Design – Description of Universe and Final Answer Sheet) as well as the two parts that make up Challenge Round 1 (Supporting File S2. Escape Room Design – Challenge Round 1: ASN and Find the Floor) and start the timer!

Figure 1. This escape room follows a linear design where each Challenge Round provides vital information for the next. The solution to each Challenge Round will provide a clue or cypher that indicates where the next set of questions can be found. When students have solved all four rounds, they present their solutions to the instructor to save the day.

Challenge Round 1: Always, Sometimes, Never (ASN) and Find the Floor

Challenge Round 1 is the only round designed with two parts:

1. Always, Sometimes, Never (ASN) – Remember and Understand
   - Students are given eight statements and must determine and explain if the statement is always, sometimes, or never true
   - The correct answers spell out the location/item (stairs, chair, etc.) where the next clue is hidden on/near.

2. Find the Floor – Apply
   - Students are given a math-based problem.
   - The correct answer is a positive integer that indicates which floor the next clue is hidden on.

ASN Questions

The ASN questions, originally developed by Swan and Ridgway (10), enhance a traditional true/false question by including an intermediate "sometimes" option. The ASN questions are often most effective when they address common mistakes or key misconceptions. The American Association for the Advancement of Science has published a list of misconceptions in life science, physical science, earth science, and the nature of science that may be helpful in generating question ideas (11). An example ASN question is:

Mutations are changes in the DNA sequence that affect phenotype.

A - Always
L - Sometimes
E - Never

Answer: Sometimes, because there are multiple DNA base pair sequences that encode the same amino acid. It is possible that a change in the base pairs, or a mutation, would result in the same amino acid sequence, and therefore a fully functional protein that would not ellicit a phenotype. These mutations are called silent mutations.

For use in the game, each answer is associated with a letter, similar to a multiple-choice question. When the letters corresponding to the correct answers from each question are written out in order, they spell out a location hint for the next set of questions. To make sure students cannot simply guess the correct answers, multiple words should be embedded in the answer options such that a wrong set of answers could still produce a non-applicable word (such as oven). In my experience, most groups initially arrive at incorrect answers, but since their answers lead to a non-sense or unhelpful word they go back and recheck their answers. The template provided (Supporting File S2. Escape Room Design – Challenge Round 1: ASN and Find the Floor) has the question layout for eight questions for 10 teams with location clues such as bench, chair, etc. You should create a question bank ~2-3 times larger than the number of groups participating in the Escape Room so that you can mix and match questions to create a unique set of eight questions per group. For instance, for 10 teams my question bank consisted of 26 questions. If you are planning a shorter game, you should use fewer questions per team.

Find the Floor

The second half of Challenge Round 1 will tell groups more information about where to find their next set of questions. Students are given a math question with an integer answer that matches the floor where the location clue (chair, bench, plant, etc.) is located. Based on the math question you are having them solve, you may need to be clever and have them select the digit in the 10's or 1's place if you want to use floors, or you could design the problem to provide a specific room number, etc. You only need the number of questions as you have floors or rooms accessible to you. For instance, I made four questions because my building had four floors on which to hide clues. Having their location and floor clue, students can search for their hidden envelope containing Challenge Round 2 questions. To ensure the teams know they found the right envelope, each envelope should be labeled with the correct team number.

Challenge Round 2: Color Coded Matching

Inside their hidden envelope students will find three items:

1. a map/matrix for envelopes set up on the board in the main classroom for the game (Supporting File S4. Escape Room Design – Challenge Round 2: Color Barcode Envelope Map),
2. a color-coded equation sheet (Supporting File S5. Escape Room Design – Challenge Round 2: Color Coded Equation Sheet), and
3. the second set of challenge questions (Supporting File S3. Escape Room Design – Challenge Round 2: Color Coded Equation Questions).

Color Coded Matching – Analyze

- Students are given eight problems/questions and an equation sheet that is color coded to equation type (i.e., general, chemical reactions, phase changes, etc.) and are asked to determine which equations are needed to solve each problem.
- The correct answers will produce a list of equations used from each equation color category. Listing in order the total number of red, green, blue, etc. equations used for the solution creates a number bar code that indicates the correct envelope for their team on the envelope map.

The question sheets should indicate how many total equations/relationships were needed to solve the problem. An example would be:

You have a reaction with a $\Delta G^o = 5.8$ kJ/mol at 298 K.

a. Is this reaction favorable or unfavorable?
b. What is the K_{eq} for this reaction.
c. You want to couple the reaction with ATP hydrolysis, for which $\Delta G^o = -30.5$ kJ/mol. What is the new equilibrium constant for the reaction when it is coupled with ATP assuming that ATP, ADP, and Pi have a concentration of 5 mM, 6 mM, and 2 mM respectively. [2 total equations needed]

Again, you will need a question bank ~2-3 times larger than the number of groups to create different question sets and barcodes per group. Once the students determine how many of each colored equation/principle they need to solve the problem, the envelope map instructs them to alphabetize the colors, and then write the number of equations of each color type in order. For instance, the students may have used yellow equations six times, blue equations two times, pink equations four times, and green equations one time. The bar code generated would be "2146", corresponding to blue - green - pink - yellow. The students then find this barcode on the map to determine which envelope on the board belongs to them. To prevent the students from guessing as envelopes are removed from the matrix, extra envelopes are included as decoys. When a group selects an envelope, they will know they are correct if their group number is written on the back. If a group picked a decoy envelope, or another group's envelope, they would need to return the envelope to the board, check their answers, and try to determine where they made a mistake to fix their barcode. Groups can continue to attempt a solution until they find the correct envelope.

Challenge Round 3: Rank the Options

Inside the correct envelope, students will find a single piece

of paper with their third challenge question (Supporting File S6. Escape Room Design – Challenge Round 3: Rank the Options Question).

Rank the Options – Evaluate

- Given a set of four possible antidotes (or reagents, temperatures, etc.) and their properties, students need to determine which ones will be effective based on scientific concepts covered in class.
- The correct answer leads to a specific container that holds the last clue.

For this challenge, you will need approximately as many "antidotes" or conditions as groups to allow for enough variation between groups. I provided each group two antidotes that would be effective and two antidotes that would be ineffective. To ensure students go through the calculations and digest the results, I asked for the second most effective option as the final answer. An example question would be:

Rank from best to worst, which of the four chemicals listed below would be able to remove the zombie plasmid from the water at 37°C based on the enthalpy and entropy of mixing the plasmid with water (a model for blood) and mixing the plasmid with your chemical.

Chemical	$h_w - h_c$	$s_w - s_c$	$\mu_w - \mu_c$
B	-340	-5	
D	-50	75	
G	100	25	
F	250	-15	

When designing your own "antidotes" and rankings, make sure you have only a few correct answers (I had 3/10 correct antidotes) and some answers that are incorrect for all the groups as further described in the supporting files (Supporting File S6. Escape Room Design – Challenge Round 3: Rank the Options Question). Each second best chemical letter corresponds to a labeled bowl or container with the chemical letter label facing a wall so that student cannot see the options ahead of time. Once students find an answer, they can go to the containers and see if the answer they found has a corresponding container. If they do not find the chemical letter, they know they have to re-asses their work. If they picked one of the incorrect answer bins, they would find a piece of paper telling them their answers was wrong and they needed to try again. Selection of the correct bin would provide them with the question for the final challenge.

Challenge Round 4: Find the Antidote

The final challenge question asked students to determine which of two antidotes would cure the zombie virus based on experimental, numerical, or graphical data provided to them. This question lends itself well to identification of laboratory techniques, interpretation of data or designing a sequence of experiments to solve a problem. I had students determine which of two enzymes would work better based on given reaction rates (Supporting File S7. Escape Room Design – Challenge Round 4: Find the Antidote). They were provided data for each set and had to perform calculations based on two different types of approaches to compute chemical rate constants (i.e., Arrhenius and Transition State Theory). I placed this last challenge at the 'evaluate' level of Bloom's Taxonomy, but asking for an experimental procedure would put it at the 'create' level.

Once students have determined the answer to the final puzzle, they inform the instructor of their proposed solution and turn in their final answer sheets (Supporting File S1. Escape Room Design – Description of Universe and Final Answer Sheet), along with their ASN explanations. If they are correct, they have completed the Zombie Apocalypse Rescue Mission, saved the day, and successfully escaped certain death! If they did not obtain the correct answer and there is still time remaining, the instructor can provide them with feedback and give them another chance.

SCIENTIFIC TEACHING THEMES

Active Learning

This activity puts students in groups and has them collaboratively engage in problem solving. It also provides a memorable and somewhat emotional experience around which to organize information and shifts in understanding. Previous studies have shown that emotional triggers improve memory (12). To further enhance the learning objectives, students should be asked to reflect on their teamwork, which content mistakes surprised them, and which of their strategies to solve the problems did or did not work (13). To reduce stress of the game and enhance the quality of the reflection, this should be done once the team has finished the challenge or time has expired.

Assessment

The escape room primarily functions as a means of self-assessment for the students because they receive informal feedback on their success after each round. Instructors also obtain informal feedback on student understanding based on how quickly the students move through the challenges and how many times they arrive at incorrect answers before succeeding.

Inclusive Teaching

As this activity is based on group work, it helps to foster a learning community within each group and promotes the exchange of ideas and collaboration. Using randomized groups also helps students to hear perspectives that they may not usually hear.

IMPLEMENTATION TIPS

If you are using this activity outside of class, you could offer extra credit or small gift cards for campus venues or coffee to boost participation. We provided a small amount of extra credit points for the team that finished first (5 pts), second (4 points), third (3 points), and every team that completed the challenge (2 pts). In our case, we initially set a time limit of three hours, but all teams finished within 2.5 hours, and the fastest group completed the task in 2 hours.

I found that groups wanted to check their answers before going to find their hidden clues in Challenge Round 1. I allowed this because it gave me the opportunity to provide them with feedback. However, limited availability of instructors can

cause stress in a time sensitive game. For eight groups, two instructors is the minimum to keep up with questions. If you do not want to allow answer checking, the game has enough built-in checks that the students should be able to receive feedback from the game directly. Make sure to tell the students that the game will give them feedback based on group number labeling so they know that they do not need you to confirm their answers.

A major potential issue is non-inclusive groups. This can lead to confusion for students who are struggling with the material. Keeping groups small, preferably five or fewer students, should help to encourage participation. If this is still an issue, you may need to implement checkpoints where a randomly selected student per group needs to explain one question from the previous round. If the student is unable to explain the question, you could assign a 15 minute penalty to their time.

From the instructor point of view, the most important thing to do is to make sure your answer keys are correct and that you have an accurate layout of all the clues. Creating a full layout of materials and locations before beginning is imperative. For each instructor present for the game, you should make a copy of the solutions so that all instructors are able to help answer questions or re-direct students who made minor mistakes. A full list of supplies and when to provide them are given in Supporting File S1. Escape Room Design – Description of Universe and Final Answer Sheet. Sample answer keys and timing tips are found throughout the supporting files for each Challenge Round.

INSTRUCTOR AND STUDENT REACTION

Students were excited to try the escape room. Discussion started immediately and remained focused throughout. Students engaged deeply in conversation with each other when they realized their answers were incorrect, and they used both logic as well as information from the class to arrive at a solution. Challenge Round 1 and 2 (ASN Questions and Color Coded Equations) was especially effective at promoting theoretical conversation between group members.

Students felt encouraged by the game. One student commented that the game was reassuring: “Having to focus on completing the task helped me not to overthink problems and I realized I know the material better than I thought I did!” Another student commented on her engagement level: “Usually I end up checking out at review sessions, but this was really helpful because we covered so much material and I stayed focused the whole time.” Many students commented on how much fun it was to play, and how it helped them to study without getting stressed about the exam but rather to keep trying to get the right answer instead of giving up.

SUPPORTING MATERIALS

- S1. Escape Room Design – Description of Universe and Final Answer Sheet
- S2. Escape Room Design – Challenge Round 1: ASN and Find the Floor
- S3. Escape Room Design – Challenge Round 2: Color Coded Equation Questions
- S4. Escape Room Design – Challenge Round 2: Color Barcode Envelope Map
- S5. Escape Room Design – Challenge Round 2: Color Coded Equation Sheet
- S6. Escape Room Design – Challenge Round 3: Rank the Options Question
- S7. Escape Room Design – Challenge Round 4: Find the Antidote

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