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The Green Escape Room: Part 1 – A Race to Solve an Environmental Engineering Problem by Applying Engineering Principles and Deciphering Clues and Puzzles

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Abstract

Educational escape rooms are a form of gamification that have been used in higher education and industry to enhance team building and increase motivation by making learning exciting. In general, educational escape rooms have teams solve a problem using puzzles, clues, and hints in a limited amount of time. Two escape rooms were developed for seniors in our environmental engineering program. The first escape room was centered on a hazardous waste incineration problem that included, the Ideal Gas Law, gaussian dispersion, and risk assessment. This escape room was used in our Solid and Hazardous Waste course to help our seniors prepare for the Fundamentals of Engineering Exam. It was also piloted with two faculty teams during a summer teaching seminar. The second escape room was built around an engineering ethics case study in our capstone design course, which will be discussed in the companion paper. Assessment and evaluation of these exercises revealed that most students and faculty appreciated this alternative approach to engage with the material. A valuable lesson learned is that escape room creators must be careful not to design puzzles that are exceedingly challenging and time consuming.

Introduction

Gamification is the use of game elements in a non-game application (Becker 2021). Educational games are typically based on constructivist learning theories that promote active learning (cf. Cavanagh, 2019) and metacognition (cf. Melero and Hernández-Leo, 2014). Educational escape rooms are a form of gamification used in higher education and industry to enhance team building and increase motivation by making learning exciting (da la Flor et al., 2020). In general, these rooms require teams to solve a problem using puzzles, clues, and hints in a limited amount of time (Davis and Lee, 2019; da la Flor et al., 2020). Recently, escape rooms have been applied in undergraduate engineering courses to improve students' motivation to learn, increase participation (Davis and Lee, 2019; da la Flor et al., 2020), and to practice skills (e.g., communication, teamwork, and creativity) that traditional lecture mode classrooms might not (Bodnar et al., 2016). Examples of an escape room learning exercise in an undergraduate environmental engineering program were not found in a search of the literature. Two escape rooms were developed for seniors in our environmental engineering program as part of this initiative. The purpose of this paper is to present a framework for an undergraduate engineering escape room active learning exercise using a case study as an example. The escape room described in this paper centered on a hazardous waste incineration problem that included, the Ideal Gas Law, a gaussian dispersion model, and carcinogenic risk assessment. This exercise was used in an undergraduate Solid and Hazardous Waste course at the United States Military Academy to review course material and selected subjects on the Fundamentals of Engineering Exam (FEE). In addition, a slightly modified version of the escape room was offered as an ancillary exercise during a faculty summer workshop to help build faculty teamwork, to demonstrate an alternative learning tool, and to further assess the escape room's strengths and weaknesses. The second escape room was built around an engineering ethics case study in our capstone design course, which is discussed in the companion paper.

Approach

An engineering escape room can be developed using the framework presented in the following eight steps. Clues, puzzles, and attributes that impart an escape room feel are presented as examples that can be adapted into a variety of engineering learning exercises.

1. Develop a quantitative problem and solution. A hypothetical hazardous waste incineration problem (Figure 1) was used as the foundation of our escape room exercise. This problem was selected for the escape room exercise because it lends itself to piecewise solving. Briefly, a leaking underground storage tank (UST) contaminated a sandy soil with benzene on the East shore of Lake Liebig. As part of the planned remediation scheme, the benzene will be removed with a soil vapor extraction (SVE) system and burned in an incinerator. A group of citizens has vowed to stop the project because they are concerned about children on a school playground 1-km directly downwind from the site. Students must determine if the cancer risk at the playground is acceptable when the incinerator achieves or exceeds the Environmental Protection Agency's destruction removal efficiency.

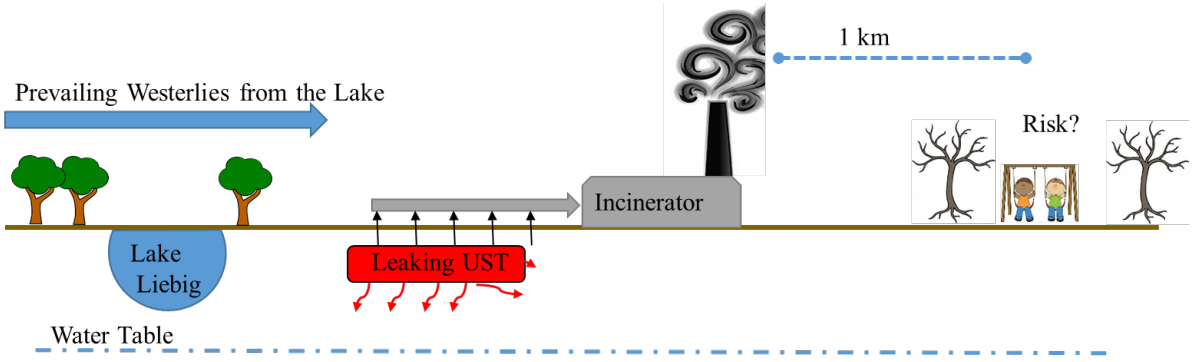

Figure 1. Sketch of the Overarching Quantitative Problem

2. Create an overarching puzzle that will be completed in parallel with the quantitative problem. A crossword puzzle was used to create a parallel overarching component, with an embedded final message, which must be decoded to escape from the room. The puzzle helped link components of the overarching problem and allowed students to multitask during the exercise. In addition, our puzzle included additional environmental engineering concepts

that were used to help students review for selected topics on the FEE.

3. Break the problem into modules that must be solved sequentially. We propose that educational escape room puzzles should have cycles of both challenging (create tension) and straightforward (release tension) sections akin to improvisation in a musical composition. In addition, it is beneficial to incorporate common educational misconceptions as "puzzling elements" to strengthen the educational value of the puzzle and to stay in alignment with the puzzling nature of the escape room design. Our escape room was broken into seven modules that generally followed the steps required to solve the (hazardous waste incineration) overarching problem. Most of the modules contained both components of the overarching problem and crossword puzzle clues. Simulated antique paper and riddles were used to create an authentic escape room feel as show in Escape Room Module (Challenge) One (Figure 2).

Congratulations! Because of your reputation as a scholar and leader, you have been placed on a team that will protect innocent children. But safeguarding the children is not enough, to escape you must also identify the secret phrase!

Can your team be the first to escape from this environmental engineering box and win the merch on the outside?

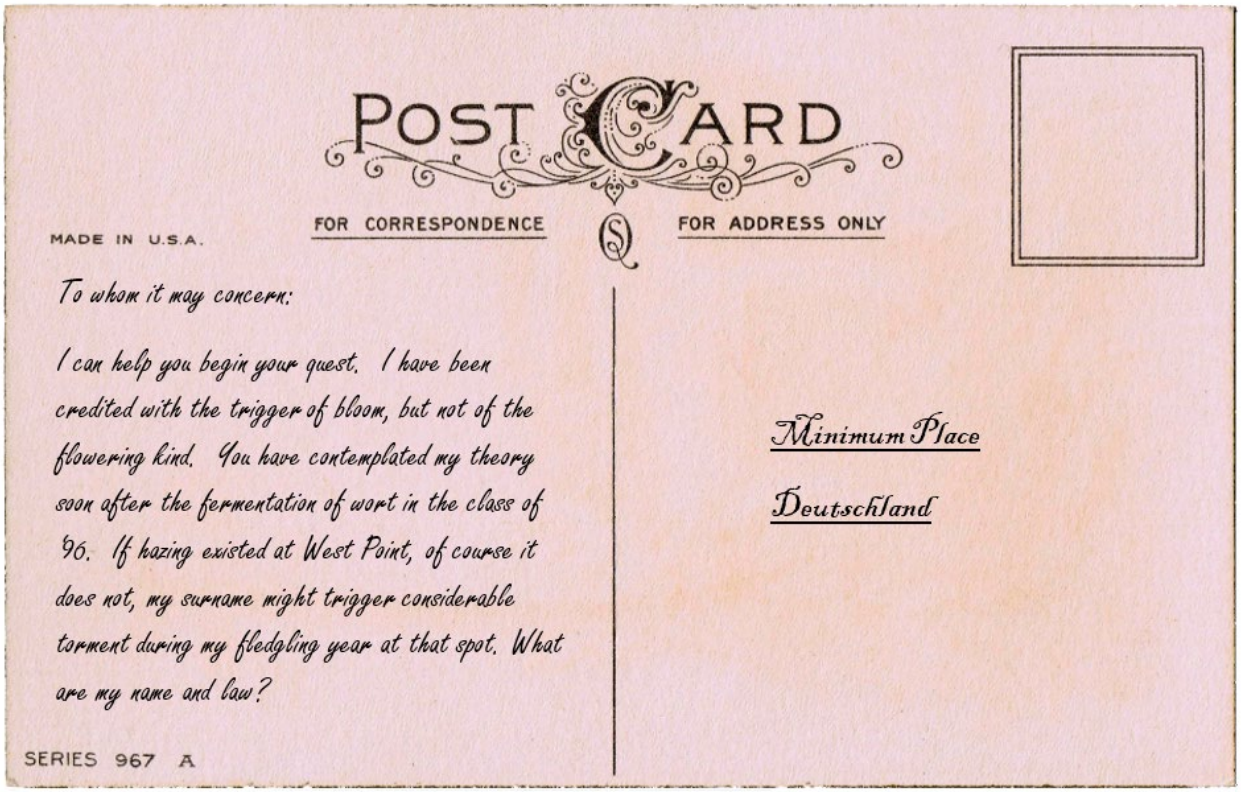

Figure 2. Escape Room Module (Challenge) One.

After each group successfully demonstrated completion of one module, the clues for the next module were hand-delivered in a sealed envelope. An example of a module that required a calculation is presented in Figure 3. In this case, the riddle to be solved was finding the carcinogenic risk *numerically equivalent* to one part per million (1 ppm): 10^{-6}. In their haste to complete the problem, several groups mistakenly used 1 ppm as an airborne concentration, which made this a challenging aspect of the experience.

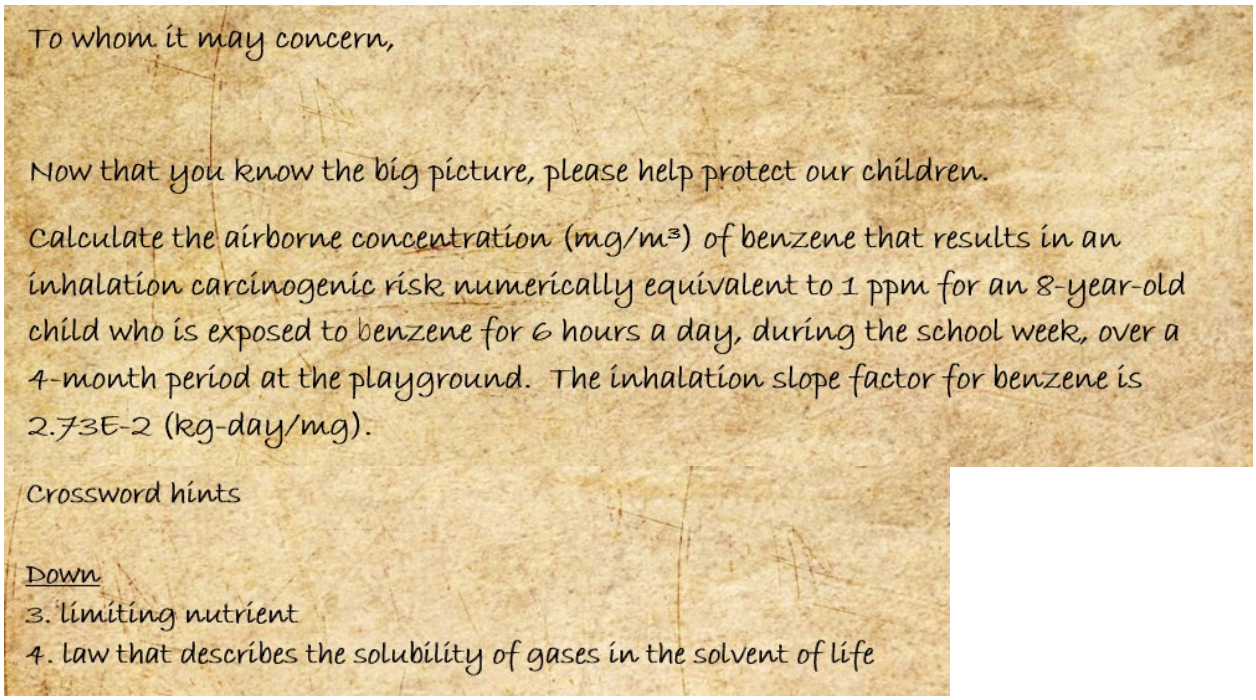

Figure 3. Example of Quantitative Escape Room Module

We strove to make the escape room experience attractive to students who prefer different problem-solving approaches by adding a variety of puzzle types. For example, we used a rebus puzzle (not shown), which allowed students to discover the 1-km distance between the incinerator and playground. Students were directed to find the puzzle on our course Blackboard site. One module included a QR code that provided a hint to use the Ideal Gas Law to solve the quantitative problem (Figure 4). The students had to discover the QR code.

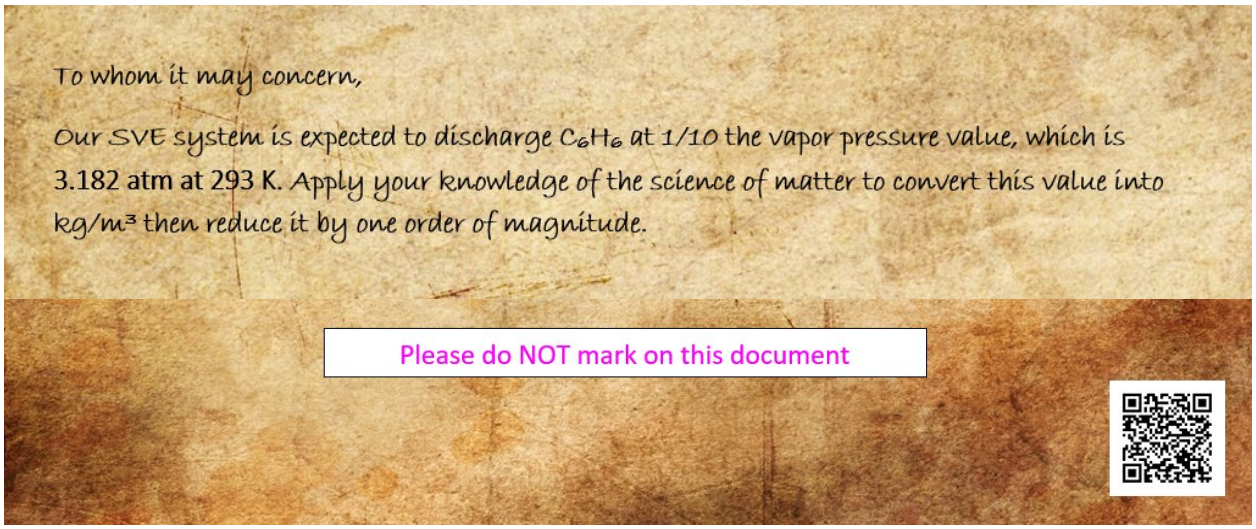

Figure 4. Module with QR Code. Students were not directed to use the QR code, which provided a "free" hint to use the Ideal Gas Law.

A MicroSoft Excel file (see Figure 5 for a screen shot), made available via Google Docs (one link for each group), was used to provide an answer check in one module. Students were required to enter their numerical answer into the yellow cell. A secret code was produced when the correct answer was entered, which was then reported to the instructor. The secret code was concealed in Excel by using a password protected, hidden cell.

Enter your answer in the yellow cell (kg/s):		We're sorry, please try again

Figure 5. Excel answer check

4. Develop a set of instructions that outlines resources and the timeline. The complete set of instructions is presented in the Appendix. Briefly, we divided the student population (15 in 2021) into teams of three and we attempted to place students with a "puzzle solving mindset" on each team to level the playing field (the instructor spent 1.5 semesters with the students and attempted to use his experience to identify those who might excel in an escape room environment; team composition is discussed in more detail below under lessons learned).

Each team was directed to report to a predetermined location (mostly small classrooms) at the start of the lab period. Teams were separated such that they were unable to overhear the discussions of other teams and any hints that we provided. We used small classrooms with chalkboards and computer projectors to encourage teamwork during problem solving. The escape room exercise was split into a total of two laboratory periods (ca. 4 hours). Teams who did not escape during laboratory period one were given the option to complete the unfinished module, at the end of the first laboratory period, during the time between laboratory period one and laboratory period two. The instructor team used Microsoft Teams to communicate with groups during the exercise, which expedited communications. In addition, we used one instructor and one staff member during the exercise to minimize time that groups waited for assistance. The need for an instructor team is discussed in more detail below.

5. Develop a grade scheme. The instructions stated that every group who escaped by the end of the second lab period would earn an A+ (25 points in a 1000-point course) unless points were deducted during the exercise itself. Points were deducted for the following reasons: one point for each web search term used and one point for each hint provided by the instructors. If a group did not escape by the end of the second laboratory period (all groups escaped), then the group's grade would be based on the number of exercises completed. Students were informed that the first group to escape would win a prize (gift certificates to a local restaurant) to incentivize on-time completion and to promote friendly competition.

6. Test the escape room prior to go-time. We discussed the modules and puzzles prior to execution to ensure that puzzles were not too challenging for the time allotted. The overarching problem was adapted from a previous semester and assessment at that time indicated that the level of difficulty was appropriate for the course. This topic is discussed in more detail below under lessons learned.

7. Execute the escape room. One faculty member and one staff member worked with the five student groups during the exercise. The faculty and staff were required to communicate on Teams to check answers as well as visit groups in their rooms during face-to-face

engagements. Face-to-face was used primarily for helping students overcome challenging issues and provide hints when necessary.

8. Assess and evaluate. A short survey, using a satisfaction Likert scale, and a few open-ended survey questions were administered on the following lesson. The data were thematically analyzed to identify general themes and areas for improvement.

Assessment and Discussion

The purpose of this assignment was to help students review course material and subject matter associated with several subjects on the FEE. Unfortunately, FEE results provided by NCEES do not provide sufficient precision to enable useful assessment of the escape room exercise. However, because the escape room exercise was adapted from an individual homework assignment with essentially the same underlying calculations, comparison of performance on both exercises is possible. A Student's t-test revealed that the average grade on this assignment improved ($P < 0.0194$) from 88% as an individual homework assignment (2017-2020) to 97% as the new escape room exercise (2021-2022). While this result is encouraging, it is based on two semesters of escape room data, the exercise changed from an individual event to a group event, and there was a new instructor in 2022. It is thought that subjective assessment data, discussed below, is more relevant.

A survey of our students following the exercise in spring 2021 and 2022 is presented in Table 1. The assessment results suggest that most students were motived by and appreciated the escape room active learning environment, which is consistent with results reported elsewhere (de la Flor et al., 2020). Although 100 percent of the students believed that sufficient time was provided to complete the exercise in 2021, the instructors provided additional "free" support to help several teams escape prior to the time limit. Consequently, the escape room was revised in 2022 to enable completion in a shorter timeframe. In particular, the rebus puzzle was simplified because it was excessively challenging for all teams. Survey results in 2022 suggest that there was generally a higher level of satisfaction.

Table 1. Student feedback on the escape room exercise

Spring 2021	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Percent Who Strongly Agree or Agree
The Escape Box Exercise helped me prepare for the fundamentals of Engineering Exam (FEE).	2	8	3	2		67
The Escape Box Exercise was an engaging approach to review environmental engineering topics.	5	9	1			93
I learned something by participating in the Escape Box Exercise.	3	11	1			93
The Escape Box Exercise encouraged teamwork.	5	8	2			87
The allotted 4 hours was sufficient to complete the Escape Box Exercise.	4	11				100
Spring 2022	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**	**Percent Who Strongly Agree or Agree**
The Escape Box Exercise helped me prepare for the fundamentals of Engineering Exam (FEE).	0	9	1	0		90
The Escape Box Exercise was an engaging approach to review environmental engineering topics.	5	5	0	0		100
I learned something by participating in the Escape Box Exercise.	2	6	1	1		80
The Escape Box Exercise encouraged teamwork.	5	5	0	0		100
The allotted 4 hours was sufficient to complete the Escape Box Exercise.	5	5	0	0		100

Examples of positive open-ended student feedback included the following (second three from 2022):

- *I really liked the crossword aspect and the broad range of courses covered on the problems. The group of 3 was also helpful.*
- *Some of the riddles were fun and it was interesting to see problems presented in a different format.*
- *I liked how there were lots of real-world problems that connected to one another.*
- *It had a perfect level of difficulty! I also enjoyed how everyone (student and instructor) were committed to making this a fun, worthwhile experiment.*
- *I appreciated using the format of competition to encourage studying. I had a good time feeling like I was racing my peers and got to know my classmates more.*
- *The two-part problems, having the cross word and the question on the same sheet allowed everyone to have a part in solving the problem.*

Examples of areas for improvement included the following student comments (second three from 2022):

- *Two-person teams would allow for better FEE preparation especially if you pair confident/competent students with those who feel they are struggling.*
- *Some of the clues were not super helpful (the "number one") but overall it was pretty fun even if it was a bit stressful.*
- *The first questions about Liebig's Law of the Minimum was very difficult because we had to say "of the minimum" part to be correct and I don't even remember the last time I had the whole law in class.*
- *It could be explained that all of the questions used answers from the previous questions. For the last exercise, we were scrabbling because our answers were all over the place.*
- *Some times [correspondence] between the instructors and the groups were a [little] slow because they had to physically go to each group. One way this could be improved could be through some sort of form that could be filled out, where if you get the right answer the next clue would unlock.*
- *Maybe just like a 5 min pep talk in the very beginning to explain the mechanics of the event? We had some trouble which was ultimately solved by reading the directions but who starts anything by reading the directions these days.*

Evaluation of the student assessment data suggest that the experience was a success with areas for improvement (vide infra). In 2022, two students commented that they responded negatively to question 3 (I learned something) because the exercise was a review of material that they had learned in the past. Lessons learned are discussed below.

A modified version of the escape room discussed above was administered to faculty during a summer faculty workshop to demonstrate an alternative means of teaching and assessing and to receive feedback on the exercise. The exercise was simplified to be completed in two hours but used the same over-arching problem. A survey of the faculty following the exercise revealed the assessment results presented in Table 2.

Table 2. Faculty feedback on the escape room exercise

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Percent Who Strongly Agree or Agree
The Escape Box is effective as a learning tool.	4	1	1			83
The Escape Box reinforce concepts learned in environmental engineering courses taken at USMA.	5	1				100
The clues provided during the Escape Box exercise were fair and solvable.	1	2	2	1		50
The time provided to complete the Escape Box exercise was appropriate.	1	3	1	1		67
An improved version of the Escape Box exercise should become a regular part of New Instructor Training.	3	1	1	1		67
The Escape Box exercise encouraged team building.	3	2	1			83

Faculty who participated in the exercise responded particularly constructively regarding the escape room's effectiveness as a learning tool, its ability to cover a broad range of topics, and its

ability to foster team building. The difficulty associated with some puzzles and the allotted time were noted as areas for improvement.

Lessons Learned

This was the first escape room learning experience created for the Environmental Engineering Program at our institution. While assessment and evaluation revealed that students and faculty appreciated the exercise there is room for improvement. Examples of lessons learned are presented below.

- Puzzle designers should have disinterested parties test puzzles in advance for level of difficulty, universal design (inclusivity), and outdated pop-culture references. (This was addressed in the revised exercise in 2022.) In addition, the time needed to complete the exercise should be pilot tested in advance. Simply talking through problems is not sufficient to assess difficulty level.
- Ad hoc discussions with students after the exercises revealed the instructor was successful in identifying students with a puzzle solving mindset in most cases (they shared that they enjoyed solving the puzzles in the exercise.) However, identifying students with a puzzle solving mindset *a priori*, would be unlikely if we had a larger student population or less experience with the students. Perhaps a survey of the student population prior to execution would provide some insight on how to evenly balance groups. Others have allowed students to choose their escape room partners with mixed results (Heckelman and Bucholz, 2020).
- The faculty member and staff member were highly engaged with groups during much of the exercise. It would have been helpful to have additional faculty or staff members prepared and ready to assist during busy periods. This was a shortcoming in terms 2021 and 2022 due to limited staff and faculty support. An automated answer check, as suggested by a student in 2022 (see student comments above), might be an effective approach to address this concern.
- Awarding a prize to the winning team was highly motivational in both the student and faculty exercises. This aspect of gamification made the escape room exercise stand above our typical graded events.

- A considerable amount of time was required to build the escape room modules (ca. 15 hours). However, like many learning and assessment instruments, it can be used in the future with some modification.

Conclusion

An engineering escape room is an active learning exercise that can be developed by adapting the framework presented herein. Our environmental engineering escape room was an exciting and challenging method for reviewing course material and helping students prepare for selected subjects on the FEE. A considerable effort was required to build the escape room modules (ca. 15 hours), but they can be enhanced and reused in future semesters. Faculty and staff members should prepare to be highly engaged during execution of the escape room exercise. Overall feedback from students and faculty suggests that, in general, escape room exercises for engineering problems are effective learning tools that should continue being used in undergraduate courses.

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Appendix A

Environmental Engineering Escape Box Instructions

Read and comprehend all instructions listed below before beginning.

- Your authorized references are limited to the following: Blackboard (Bb), Fundamentals of Engineering Reference Handbook, your engineering textbooks and course notes, computer/cellphone/web (limited use as discussed below).
- You are not authorized to get help from other people outside of your formal group.
- Do not mark the exercise handouts (except crossword puzzle), use your own paper.
- You must ask permission to conduct a web search (use Teams). I will deduct 1 point for each search term used. I am trusting you to provide me with a list of all search terms at the end of the last exercise.
- You are authorized to request one lifeline for each exercise. I will deduct 1 point for each hint that I provide.
- Do not open exercise packets without permission from the instructor. Please do not tear envelopes when breaking the seal (so they can be used in the future).
- You must always use your group number when corresponding with your instructor on Teams. Set up a Teams meeting for your group and invite your instructor.
- Contact the instructor on Teams when you have completed an exercise. The instructor will come to your room to check your progress or discuss on Teams. If you've completed the current exercise, then you will be advanced to the next exercise.
- The instructor might use email for course-wide announcements, so monitor that as well.
- You should attempt to complete the crossword puzzle (use a pencil) in parallel with the other exercises. However, the crossword answers do not have to be complete before advancing to the next stage.
- You may take your last uncompleted exercise home to finish on the first day. You must only solve this in your formal group. You may not take the crossword puzzle home.
- Groups with one or more members on Teams (remote mode) will get one free hint. Groups with team-members absent might get additional help from the instructor.
- Every group who escapes by the end of lesson 31 will earn an A+ unless points are deducted as discussed above. The first group to escape will win a prize.
- If a group does not escape by the end of lesson 31, then the group's grade will be based on the number of exercises completed.
- Please keep your room door closed, if in a small room.
- After completion of the last exercise (after you have escaped), you will combine all your work, list of web search terms, documentation (cover sheet), and submit to your instructor.