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The Green Escape Room: Part 2 - Teaching Students Professional Engineering Ethics by Applying Environmental Engineering Principles and Deciphering Clues and Puzzles

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Abstract

Escape rooms use a sequence of related clues and puzzles to lead participants to a final answer. While escape rooms have been used in technical aspects of engineering education as an active learning exercise, very few have been applied to ethics and none to engineering ethics as reported in the literature. Conventional ethics education is often taught by lecture and passive analysis of case studies which does not actively engage students with ethical principles or codes like the National Society of Professional Engineers (NSPE) Code of Ethics. The objective of this work is to evaluate escape rooms as a tool to improve student's understanding of professional engineering ethics. The escape room exercise in this study is geared towards environmental engineering students, engaging them with relevant subject-matter problems including water treatment, wastewater treatment, and solid waste management in the developing world. Each technical problem is compounded by an ethical dilemma and participants must justify their final action to resolve each problem by using the NSPE Code of Ethics. To measure student learning, a NSPE-developed, 25-question, True-False quiz designed for professional engineers is administered immediately before and after the escape room exercise. Of 17 participants, the ethics escape room improved the average participant's grade on the NSPE quiz by 7.8% ($p=0.002$). All participants agreed or strongly agreed that the ethics escape room was "effective as a learning tool," "should become a regular part of ethics education," and "encouraged team building," on a feedback form administered prior to the post-quiz. This work demonstrates the effectiveness of the escape room as a format for active learning in engineering ethics education and provides an outline for ethics education in a wide range of professional disciplines.

1 Introduction

Engineering ethics is the study of moral issues, decisions, conduct, character, ideals, and relationships of individuals and organizations involved in engineering and technological development [1]. Across all disciplines of engineering, ethics is a required course component of undergraduate engineering education and is included on the Fundamentals of Engineering (FE) and professional engineering (PE) examinations. At the undergraduate level, there is only a broad requirement by ABET for students to have "an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts" [2]. The National Council for Examiners of Engineering and Surveying (NCEES), made up of the engineering and surveying licensure boards in the United States, administers the FE and PE examinations and established the *Model Rules of Professional Conduct* that serves as guidance for state engineering licensing boards. However, *Model Rules* are just one set of codes of ethics. The National Society of Professional Engineers (NSPE), whose members are professional engineers of all disciplines, defined the *Code of Ethics for Engineers* which addresses broader ethical questions than *Model Rules* such as sustainability [3]. Given the NSPE Code of Ethics are consistent with ABET outcomes, NSPE has been referenced as one such framework for teaching engineering ethics [4].

Engineering ethics is most frequently taught as (1) individual philosophy courses, (2) brief discussions in connection with well-known cases of engineering failure, or (3) modules which extend across multiple class sessions (e.g., capstone design) [5-6]. Independent of the venue, Colby and Sullivan [4] note the lack of active learning utilized in engineering ethics education. Escape rooms are one active learning teaching strategy increasingly being used in engineering education in which a group solves a series of puzzles in a set amount of time to 'win' [7]. The gamification of learning has shown to drive student motivation [8], which can ultimately help students achieve class learning outcomes. While escape rooms have been used to teach ethical decision-making frameworks for topics such as torture [9], an engineering ethics escape room has not yet been presented in the literature. In this work, an escape room is developed and executed to teach undergraduate environmental engineering students the NSPE Code of Ethics for Engineers. This follows the development of a similar escape room in Part 1 of this paper series focused on FE review for the environmental engineering portion of the FE exam [10].

2 Materials and methods

2.1 Participants

Senior-level environmental engineering undergraduate students (n = 17) participated in the escape room exercise during the first semester of a two-semester capstone design course. Prior to the escape room exercise, students exposure to engineering ethics material was limited to individual FE exam preparation, as the topic is not formally introduced in any course prior to the senior capstone. However, a review of the students' FE exam study logs, which seniors are required to maintain in the program, showed no documented work regarding the ethics material prior to the escape room exercise. Thus, this work tests the acquisition of new knowledge as opposed to recall from previous lessons (whereas other engineering escape rooms in the literature explicitly targeted recall [10-11]). However, recall of environmental topics was helpful in solving individual puzzles.

2.2 Escape room

The escape room was framed to be a fictitious, overseas, deployed military environment where students are in charge of inspecting infrastructure for compliance both on and off a forward operating base. The complete description of the situation imagined for this work can be found in the Appendix. In this scenario, engineers and staff assigned to a military unit redeployed home (i.e., the "previous unit") without leaving proper documentation regarding current public service projects for the follow-on military unit (i.e., the "arriving unit"). The previous unit also failed to engage the local populous surrounding the fictitious base, thereby leaving a large gap for the arriving unit. Students in the scenario area are assigned to be engineers and staff members of the arriving unit, and therefore must parse through a collection of incomplete material (the "clues") from the previous unit to (1) find problem scenarios ("sites") and (2) evidence of compliance (or non-compliance) concerning environmental ethical issues. The four sites are a water treatment plant (WTP), a wastewater treatment plant (WWTP), a solid waste disposal site, and a bridge. The length of time required to solve, types and number of clues, and ethical quandary differed for each site. The first clue for each site was delivered by hand to the students and the remaining clues were hidden throughout the academic building. The first few clues for each site required process knowledge to frame the ethical dilemma. The final clue required students to cite specific components of the NSPE Codes of Ethics to justify their suggested course of action to remedy the problem, and to move onto the next site. The following sections describe the series of clues, in the form of written riddles and pictographs, for each site used in the escape room.

2.2.1 Water Treatment Plant

The first clue for the WTP was hand delivered to the students and read as follows: "I can fill an hourglass and build castles. I can go fast or slow. Some say I'm as old as time, but you may have to talk to Cleopatra about that. Find me at the end of the train, I'll capture anything suspended." The solution to the clue was a pilot-scale sand filter the students had used in a previous water treatment lab course. Once at the 'WTP,' students met the 'Operator' who claimed the previous units' response to the failing WTP was to provide a new technology, but left no direction as to what it is or how to operate it. Students solved a pictograph of 'reverse osmosis' (RO) (Figure 1) which led them to a bench-scale RO unit. Lacking engineering drawings of the RO system, students were asked to draw a process flow diagram. The final question directed students to determine where the inputs and outputs to the system from their diagram, and solve a word scramble (C T U A A I Q L A T S E N A R T L C O E) to identify the problem. The environmental problem was RO reject brine discharge into the environment and aquatic salt tolerance. Using the NSPE Code of Ethics, this ethical dilemma could be categorized under Professional Obligation 2d ("Engineers are encouraged to adhere to the principles of sustainable development in order to protect the environment for future generations") and Rule of Practice 1 ("Engineers shall hold paramount the safety, health, and welfare of the public").

2.2.2 Wastewater Treatment Plant

The first clue for the WWTP was hand delivered to students and required them to find the scale model of the campus, which included the 'smallest' WWTP in the building. The WWTP 'Operator' tells the students the WWTP treats all municipal and industrial wastewater for the base, discharges the treated water to the river, and local farmers haul off the biosolids. To determine where there may be a problem, students solve a pictograph of 'digester solids,' followed by a collage of heavy metals, to indicate there may be metals from the industrial wastewater in the biosolids farmers are land applying. When a farmer appears asking the student if they should use the biosolids, the student is faced with a few ethical dilemmas including NSPE Rules of Practice 3a ("Engineers shall issue public statements only in an objective and truthful manner"), Professional Obligations 1b ("Engineers shall advise their clients or employers when they believe a project will not be successful"), and Professional Obligation 3 ("Engineers shall avoid all conduct or practice that deceives the public").

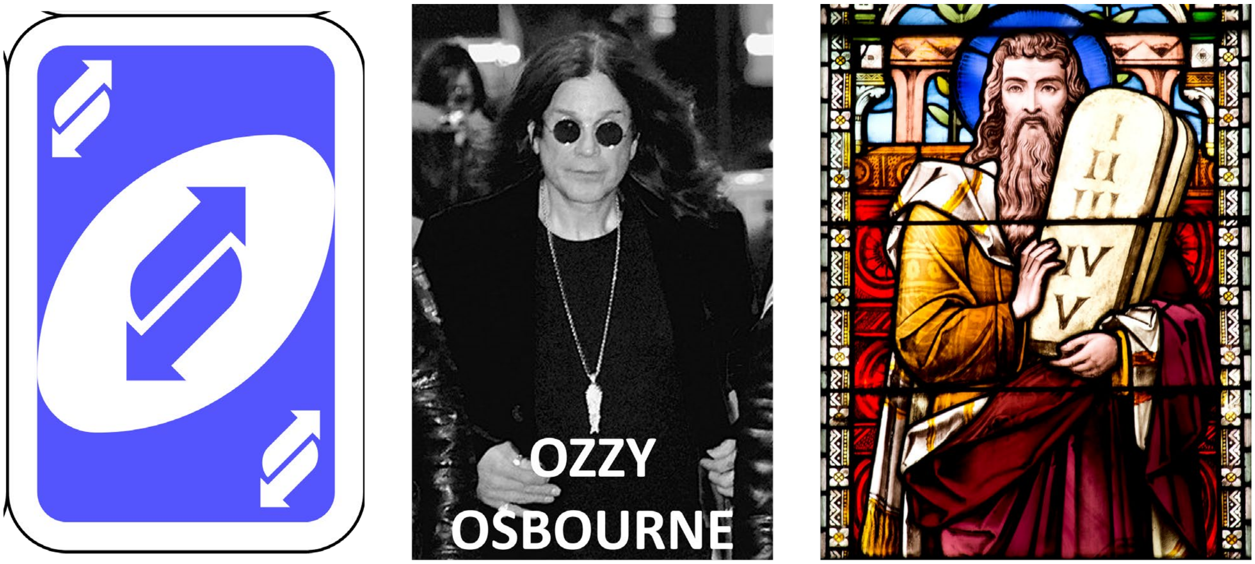

Figure 1*. Reverse osmosis clue. From left to right: 'Uno card deck' by Dmitry Fomin (CC BY-SA 2.0). 'Ozzy Osbourne in Philly' by Kevin Burkett (CC BY-ND 2.0). 'Observe the Commandments' by Fr. Lawrence Lew, O.P (CC BY-NC-ND 2.0).*

2.2.3 Solid Waste Management

For the case of solid waste management, students answer the question "how is solid waste currently being disposed of?" by solving a pictograph of "open burn pit." A trash can in the classroom has been re-purposed as an "open burn pit" by adding a label and a drawing of flames emerging from the top of the receptacle. Inside the (clean) trash can is the next clue, suggesting students follow the smoke of the burn pit. Grey clouds were printed and affixed to hallway walls outside the classroom, leading students down (and around) a few hallways to the open burn pit "site." The next clue informs students that waste is being hauled off site to an unregulated burn pit next to a small village. The village is represented by 20 images attached to a wall including a mixture of normal (e.g., children playing, people cooking) and abnormal images (e.g., soot on hands, coughing, red eyes, dead insects). Students needed to select the images that would be indicative of the smoke affecting the local village (i.e., the abnormal images). Students were to report back that the open burn pit needed to be relocated because it violated NSPE Rule of Practice 1 (see above).

2.2.4 Bridge

To diversify the case studies, a bridge project was introduced to environmental engineers. The first clue led students to a small model bridge their 'boss' had asked them to inspect. By solving a pictogram, students asked the 'clerk,' "can I see the engineering drawings?" However, the drawings were never stamped. The students' 'boss' then asked the students to review and stamp the drawings. A second pictograph is solved for the students' response: "The bridge is outside of my scope." This answer is supported by NSPE Fundamental Canon 2 ("Perform services only in areas of their competence").

2.3 Assessment

To assess learning from the escape room exercise, a set of 25 True or False questions from the NSPE were used [12]. The website prefaces that the test should be used to measure individual knowledge of specific language regarding the NSPE Code of Ethics, as opposed to general knowledge of engineering ethics. However, given the escape room activity required application of the NSPE Code of Ethics, the authors considered it an appropriate assessment tool. The full list of questions is included in the Appendix.

One question from the NSPE Code of Ethics quiz (#13) was excluded from the subsequent analysis due to conflicting information provided by the course instructor after the escape room exercise but prior to the quiz being administered. In preparation for an unrelated written assignment, the instructor suggested that when lacking subject matter expertise, a project lead should engage available experts for final report writing. The instructor did not make clear the distinction between writing reports with multiple technical experts and signing off on specific documents. The consequences were evident during the initial data evaluation, as all students answered the question incorrectly. Thus the question was excluded as it was not indicative of learning during the escape room.

2.4 Analysis

Due to the small sample size, a paired Wilcoxon signed rank test was used to determine if the students' final quiz score improved (i.e., difference in scores is greater than 0) after the escape room activity. To quantify the expected improvement, the arithmetic mean of 10,000 bootstrapped samples was used to estimate the true mean improvement (percentage point increase in final score) and the corresponding 95% confidence interval [13].

3 Results

Students completed all 4 case studies and two quizzes (pre- and post-escape room exercise) in a 2-hour class period. Overall student scores on the NSPE ethics quiz improved after the escape room exercise (Figure 2). The improvement was found to be significant by a one-sided Wilcoxon test ($p = 0.002$). A 95% bootstrapped confidence interval of mean improvement was found to be [4.4%, 11.5%], with an estimated mean improvement of 7.9%. The distribution also significantly changes from approximately symmetrical to negatively (left) skewed which suggests that some students benefited more from the exercise than others.

While student scores improved overall, not all questions saw improvement (Figure 3). Likely, this was due to the inadequacy of the NSPE quiz as an assessment tool for novice undergraduate environmental engineers. The question phrasing is pedantic and the reading difficulty, of some questions, is above the expected competency level of the students. For example, question #1 requires the distinction between 'carefully consider' and 'must.' Secondly, the escape room was not able to cover the totality of the NSPE Code of Ethics. For example, the escape room did not cover engineers in public service as evaluated in question #21.

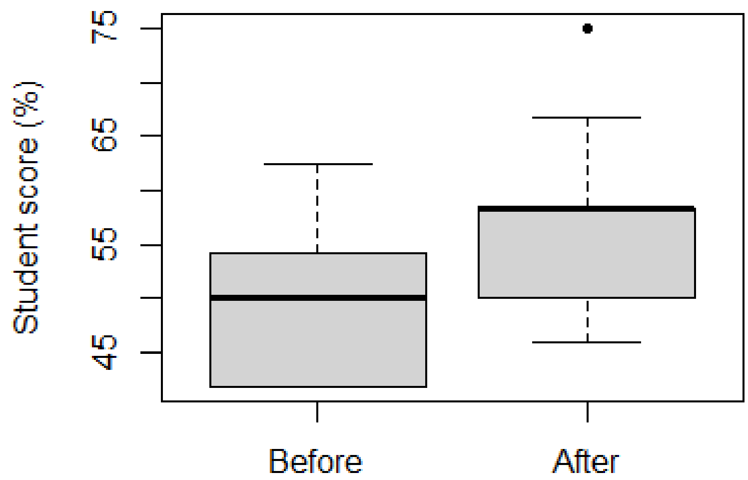

Figure 2. Overall NSPE quiz score immediately before and after the escape room exercise

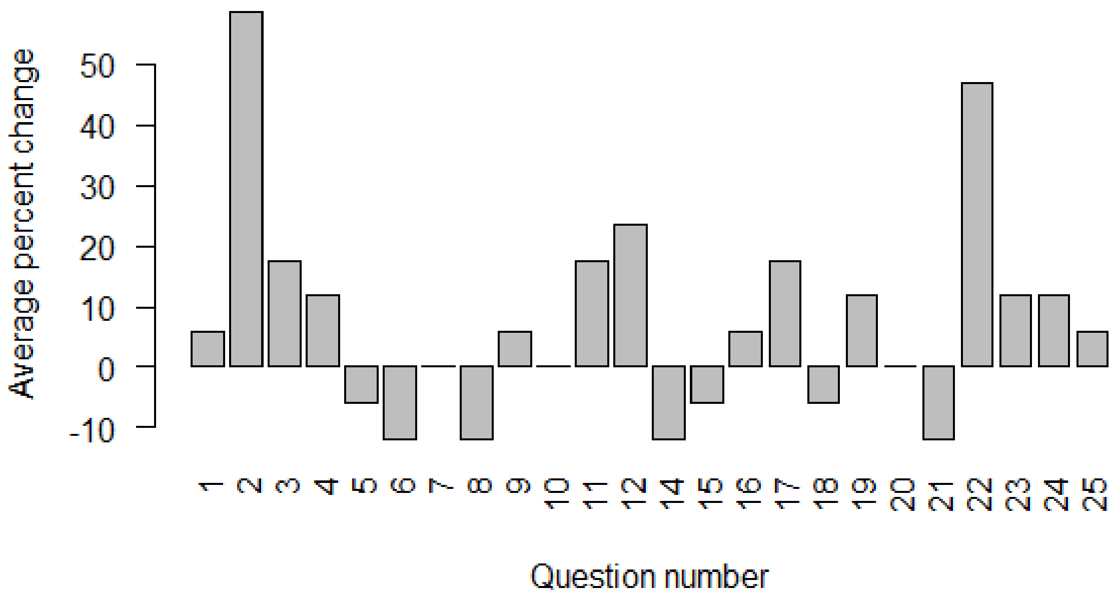

Figure 3. Average percent improvement by question where a positive percent change indicates more correct responses and a negative percent change indicates more incorrect responses.

In addition to quantitative measures of success, all participants agreed or strongly agreed that the ethics escape room was "effective as a learning tool," "should become a regular part of ethics education," and "encouraged team building," on a feedback form administered with the post-exercise quiz. The exercise continued to stand out in students' minds months later, incidentally observed in multiple students free responses to the final course survey.

4 Recommendations for Implementation

Designing a discipline-specific ethics escape box can be intimidating, but by breaking down learning objectives into individual case studies it is easier to be simultaneously imaginative and instructive. To help define lesson objectives, identify a code of ethics used widely in the discipline of interest. For a multidisciplinary engineering class, a broader code can be used such as the ABET Code of Ethics of Engineers. In selecting a code as a basis, ensure that the verbiage and detail is commensurate with the experience of the students participating in the exercise. Similarly, the method of assessment selected should also reflect the expected competencies of the students. While there are many publicly available quizzes and practice exams for engineering ethics, not all may be appropriate for this exercise depending on the experience of the students and the code of ethics used.

While it may not be possible to devise scenarios for all the principles or canons listed in a given code, ensure that the scenarios are distinct. For example, most engineering code of ethics begin by some form of "Engineers shall hold paramount the safety, health, and welfare of the public." Escape box participants should not be able to justify *every* decision by *solely* leveraging this canon, as it is important to ensure students engage multiple cannons of the code for more complex situational analysis and decision-making. Secondly, scenarios should be unique in the grounding technical material. Relying on a single technical topic for problem framing may also preclude some students from fully engaging with the ethics material.

For the portions of the code of ethics that are not addressed in the escape box exercise, it is important to develop alternative activities. For example, this escape box exercise was followed by a written response assignment in which students read through scenarios (based off NSPE's case histories), determined the most ethical course of action, and justified their choice based on NSPE Code of Ethics.

5 Conclusions

In this work, an escape room was evaluated as an alternative teaching method for engineering ethics education. The escape room exercise presented senior-level undergraduate environmental engineering students with four environmental engineering scenarios which ultimately resulted in an ethical dilemma. Students used their technical background and the NSPE Code of Ethics to justify the ethical shortcoming presented in each scenario. Students enjoyed and learned from the ethics escape room; as shown in positive feedback form responses, unprompted course survey responses, and significant improvement in NSPE ethics quiz grades. The questions in the NSPE quiz, however, are very nuanced and fairly complex–beyond the expected level of complexity for senior-level engineering students in a short time frame. Different assessment methods should be explored that are more appropriate for the expected competency level of students and better aligned with the FE exam question phrasing and scope, such as NCEES approved FE practice problems or devising new case studies which parallel the ethical pillars addressed in the escape room exercise. This work demonstrates that escape boxes can be developed for discipline-specific engineering ethics by pairing specific components of any code of ethics with case study scenarios in an interactive environment for an effective active learning activity for undergraduate engineering ethics education.

6 Appendix

6.1 NSPE Code of Ethics Quiz

***Table 1**: NSPE Code of Ethics Quiz*

No.	Question
1	It is sufficient that Engineers, in the fulfillment of their professional duties, carefully consider the safety, health, and welfare of the public.
2	Engineers may perform services outside of their areas of competence as long as they inform their employers or clients.
3	Engineers may issue subjective and partial statements if such statements are in writing and consistent with the best interests of their employers, clients, or the public.
4	Engineers shall act for each employer or client as faithful agents or trustees.
5	Engineers shall not be required to engage in truthful acts when required to protect the public health, safety, and welfare.
6	Engineers may not be required to follow the provisions of state or federal law when such actions could endanger or compromise their employer or their clients' interests.
7	If engineers' judgment is overruled under circumstances that endanger life or property, they shall notify their employers or clients and such other authority as may be appropriate.
8	Engineers may review but shall not approve those engineering documents that are in conformity with applicable standards.
9	Engineers shall not reveal facts, data or information without the prior consent of the client or employer except as authorized or required by law or this Code.
10	Engineers shall not permit the use of their names or associates in business ventures with any person or firm that they believe is engaged in fraudulent or dishonest enterprise, unless such enterprise or activity is deemed consistent with applicable state or federal law.
11	Engineers having knowledge of any alleged violation of this Code, following a period of 30 days during which the violation is not corrected, shall report thereon to appropriate professional bodies and, when relevant, also to public authorities, and cooperate with the proper authorities in furnishing such information or assistance as may be required.

No.	Question
12	Engineers shall undertake assignments only when qualified by education or experience in the specific technical fields involved.
13*	Engineers shall not affix their signatures to plans or documents dealing with subject matter in which they lack competence, but may affix their signatures to plans or documents not prepared under their direction and control where they have a good faith belief that such plans or documents were competently prepared by another designated party.
14	Engineers may accept assignments and assume responsibility for coordination of an entire project and shall sign and seal the engineering documents for the entire project, including each technical segment of the plans and documents.
15	Engineers shall strive to be objective and truthful in professional reports, statements or testimony, with primary consideration for the best interests of the engineers' clients or employers. The engineers' reports shall include all relevant and pertinent information in such reports, statements, or testimony, which shall bear the date on which the engineers were retained by the clients to prepare the reports.
16	Engineers may express publicly technical opinions that are founded upon knowledge of the facts and competence in the subject matter.
17	Engineers shall not issue statements, criticisms, or arguments on technical matters that are inspired or paid for by interested parties, unless they have prefaced their comments by explicitly identifying the interested parties on whose behalf they are speaking and revealing the existence of any interest the engineers may have in the matters.
18	Engineers may not participate in any matter involving a conflict of interest if it could influence or appear to influence their judgment or the quality of their services.
19	Engineers shall not accept compensation, financial or otherwise, from more than one party for services on the same project, or for services pertaining to the same project, unless the circumstances are fully disclosed and agreed to by all interested parties.
20	Engineers shall not solicit but may accept financial or other valuable consideration, directly or indirectly, from outside agents in connection with the work for which they are responsible, if such compensation is fully disclosed.

No.	Question
21	Engineers in public service as members, advisors, or employees of a governmental or quasi-governmental body or department may participate in decisions with respect to services solicited or provided by them or their organizations in private or public engineering practice as long as such decisions do not involve technical engineering matters for which they do not posses professional competence.
22	Engineers shall not solicit nor accept a contract from a governmental body on which a principal or officer of their organization serves as a member.
23	Engineers shall not intentionally falsify their qualifications nor actively permit written misrepresentation of their or their associate's qualifications. Engineers may accept credit for previous work performed where the work was performed during the period the engineers were employed by the previous employer. Brochures or other presentations incident to the solicitation of employment shall specifically indicate the work performed and the dates the engineers were employed by the firms.
24	Engineers shall not offer, give, solicit, nor receive, either directly or indirectly, any contribution to influence the award of a contract by a public authority, or which may be reasonably construed by the public as having the effect or intent of influencing the award of a contract unless such contribution is made in accordance with applicable federal or state election campaign finance laws and regulations.
25	Engineers shall acknowledge their errors after consulting with their employers or clients.

* This question was excluded from analysis due to conflicting information from the instructor after the escape room exercise but prior to students taking the quiz.

6.2 Situation

You are a promotable 1st Lieutenant (1LT) and graduated from West Point three and a half years ago. You earned your bachelor’s degree in environmental engineering and passed the FE exam, so have status as an EIT. Due to your excellent performance as platoon leader and company executive officer (XO), you’ve recently been selected to serve as a Battalion S4. Your battalion just deployed overseas and conducted relief-in-place / transition-of-authority (RIP/TOA) with another unit about 45 days ago. While they had been in-country for 12 months, your battalion command team has determined that they failed to adequately engage with the local populous, which has caused some friction. Local leaders are frustrated that they are unable to fix simple infrastructure problems in your area of operations (AO) – a problem they did not have prior to U.S. occupation of their area. By and large, the locals do not trust American forces.

Your Battalion Commander (BC) acknowledges that there are public service and infrastructure issues in the area but is more concerned with addressing the security threat presented by insurgents in the area. He has delegated "fixing the infrastructure problem" to your Battalion XO, who has in-turn delegated the responsibility to you saying "You have an engineering background, right? You've got this one."

Of note, there is a Civil Affairs Team that operates in your AO but is assigned to your brigade headquarters, which is located a different operating base ~80 km away. They are next scheduled to come to your AO in about 3 weeks. Similarly, there is an engineer unit that is tasked organized to your brigade but you are unclear on their construction capabilities. You do know that there is significant engineer work to be done in the large city where your brigade headquarters is located.

Your orders are to check off some major infrastructure components for compliance prior to the Civil Affairs Team visit, including: - Water treatment - Wastewater treatment - Solid waste disposal - Bridge

The previous team did not leave great directions, so you'll have to decipher some additional material to (1) find the site and (2) find evidence of compliance. Once you have found a site and solved all of the riddles, return to your XO for the next site. If you cannot solve a riddle after 5 minutes you can get a hint, and after 10 minutes you can get the answer. The team that finishes all 4 sites the quickest gets a special prize: the admiration and respect of [course instructor].

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