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Board 42: WIP: Reflections on teaching an engineering course through murder mysteries

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WIP: Teaching geotechnical engineering through murder mysteries

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Abstract

This paper discusses murder mysteries-based teaching as a basis for forensic case studies-based learning in Geotechnical Engineering. In this method, students are introduced to an engineering failure related to the topic and then asked to identify potential reasons for failure, rank potential causes, and explore a new concept cooperatively. Through this process, students comprehensively understand the fundamental principles they later encounter in abstract concepts. This approach solves a common issue with traditional teaching methods that present abstract concepts before providing real-world examples, which can hinder student learning. By using engaging and relevant forensic case studies upfront, this method captures students' attention and interest and allows them to experience the process of doing real-world engineering. The paper provides background information and methodology for developing an engineering course through murder mysteries. The course rating improved significantly, achieving a rating of 4.9 out of 5.0, the highest in the last twenty years. Comparing student performance between murder mysteries and traditional teaching in an exam shows a statistically significant result. Students in the murder mystery-style class performed nearly two standard deviations better than those in the lecture-based teaching course.

1. Background

Many students perceive Geotechnical Engineering as challenging, as evidenced by a straw-poll survey conducted in Fall 2020, which revealed that less than 12% of respondents were interested in learning about it. As a result, students often postpone taking this course, and only a fraction pursue geotechnical engineering, opting instead for more familiar streams within civil engineering. Geotechnical Engineering is distinctive, as it is the first course to introduce particulate systems (soil) rather than continuum systems (such as concrete, steel, and water). The course covers fundamental soil concepts and instructs students in designing foundations and underground structures, essential for all aspects of civil engineering. However, the course's demanding nature, which includes weekly lab work and assignments, has led to an average student rating of 3.8/5.0 over the past 20 years, compared to the organization's average of 4.1 for the same period. While student ratings are not an objective metric and be biased toward faculty's gender, age, and course grades[1], they offer qualitative feedback and a relative metric on the course's popularity compared to other offerings. The primary concern was to make this course engaging and valuable.

Students often find it challenging to learn abstract and complex concepts[2]. However, addressing critical science and engineering problems necessitates abstract reasoning. For instance, teaching linear equations is an abstract concept. Students may comprehend the process but not grasp the physical significance of the variables or how to apply them to real-world problems. Linking abstract concepts to real-world applications can be highly effective, as demonstrated by illustrating how a building deforms under the influence of forces to help students understand how linear equations are employed in real-world structural design. This method encourages students to learn through practical, tangible examples of forces and displacements rather than abstract variables (x and y), enabling them to apply these concepts to other areas. It is important to ground abstract concepts in real-world applications. Students appreciate the practical aspects and the links to real-world examples.

The objective when designing the geotechnical engineering course was to enhance student learning through real-world case histories. Traditionally, real-world case studies are often used as introductory but isolated motivational examples at the beginning of each lecture. While motivational examples can increase engagement, they do not provide knowledge discovery and exploration experiences in a problem-based setting. The geotechnical engineering course was restructured to foster an exploratory learning environment so that students could learn new concepts by investigating real-world cases. This approach naturally led to adopting of the Problem-Based Learning (PBL) framework, which emphasizes higher levels of understanding [3].

Problem-based learning (PBL) is a student-centered teaching approach wherein students work in small groups to solve complex problems without clear-cut solutions. PBL has been shown to help students "acquire knowledge, content-related skills, self-management skills, attitudes, know-how: in a word, professional wisdom" [4, 5]. The challenge involved adapting PBL to a large class setting, such as the Geotechnical course with 140 students, where the effectiveness of PBL is not well known and remains largely untested[6]. Adapting the small group interactions to a conventional lecture-based engineering curriculum is impractical without additional tutors to facilitate and monitor the cooperative learning phases in a large-class setting.

This paper explores a new approach to PBL in a large class setting using murder mysteries to discover new knowledge. The paper introduces the concept of murder mystery-style teaching through a concrete example. Then presents an overview of the course structure and students' feedback on learning. Finally, we compare students’ exam performance quantitatively after traditional and murder mystery-style teaching.

2. Murder Mysteries and Teaching Philosophy

This study adopts a murder mysteries approach to teach practical problem-solving skills and core concepts in engineering. The course structure involves presenting an example of an engineering failure related to the topic, allowing students to identify potential reasons for the failure, and then collaboratively exploring these reasons to develop a comprehensive understanding of the fundamental principles that underlie them. This approach addresses the issue of introducing abstract concepts before presenting concrete examples. Such conventional approaches can hinder learning as abstract concepts remain unclear and uninteresting to students. In contrast, murder mysteries provide a relevant and engaging context for students to learn about real-world engineering problems. Introducing geotechnical engineering concepts through murder mysteries (forensic analysis of failed case histories) is not different from the philosophy of PBL, where students encounter problems instead of facts and theories. The forensic learning model emphasizes shifting from “what is being *taught*” to “what is being *learned*.” Let us now consider how the topic of the weight-volume relationship is introduced in the murder mysteries approach and what the students learn.

Introducing Geotechnical Engineering – Weight Volume Relationship:

This is the first lecture on Geotechnical Engineering. Traditional teaching, including the prescribed textbook "Principles of Geotechnical Engineering" by Braja M. Das, introduces the weight-volume relationship as [7]:

> "*A given volume of soil in natural occurrence consists of solid particles and the void spaces between the particles. The void space may be filled with air and/or water; hence, soil is a three-phase system. If there is no water in the void space, it is dry soil. If the entire void space is filled with water, it is referred to as a saturated soil. However, if the void is partially filled with water, it is a moist soil. Hence it is important in all geotechnical engineering works to establish relationships between weight and volume in a given soil mass*."

Although the textbook elucidates that soil is a three-phase system, it may not adequately emphasize the importance of establishing weight-volume relationships. Furthermore, the critical role of water in controlling soil settlement is not explicitly highlighted in the quoted passage. Students might face difficulties constructing new knowledge and lose interest in the subject if they do not comprehend the relevance and application of these fundamental concepts. In response to this concern, let's now explore how the same concept is introduced through a murder mystery.

The case of the collapsed boiler house: "*In 2018, a healthy food firm had new owners, who spent over $400,000 for a new boiler house, which supplied steam under pressure to a food processing plant. The factory is situated near Houston, TX. Only a matter of weeks after going into full production, the boiler house was giving trouble. First, windows began to shatter, then cracks appeared in the concrete floor (Fig. 1). The local builder was unable to fix the problem.*"

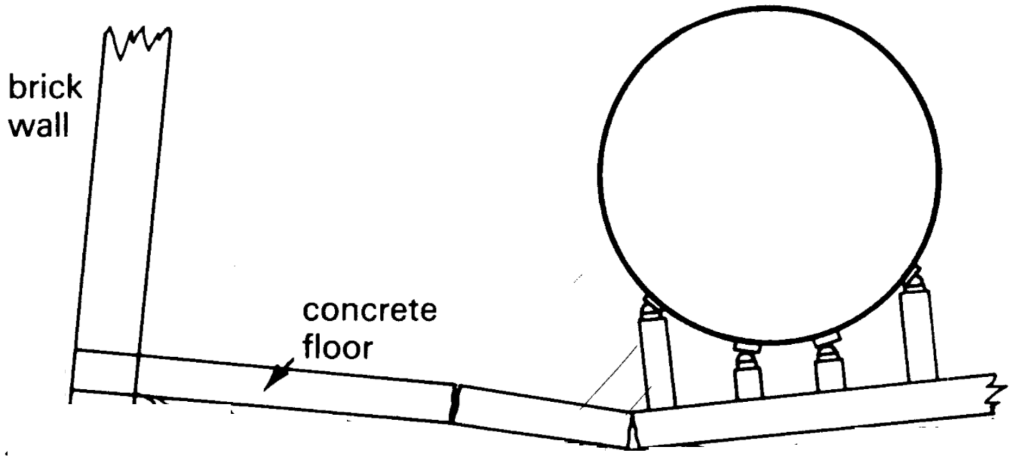


Fig. 1. The mystery of the collapsed boiler house

After introducing the case study, the students are asked to explore potential reasons for failure using their current engineering knowledge. The students are tasked with finding this reason for failure within a prescribed number of questions (typically 10). The students initially post as many questions as possible on an online platform (Menti), then collectively rank them. I then answer the top-ranked questions. The students have an opportunity to rerank other questions based on my answers. I go down the list from highest ranked to lowest. The students' questions and my answers to the top-ranked questions for solving the boiler house murder mystery in Spring 2023 are summarized in Table 1. In just six questions, the students discovered a fundamental relationship in soil - the loss of water from the soil voids (measured as weight loss in terms of water) causes soil settlement (change in the void space). Adding water to soil (measured as water content) causes swelling (measured as changes to the void ratio), whereas removing water causes settlement - this is the weight-volume relationship between water content and void ratio. Figure 2 reveals the failure mechanism for the students.

Table 1. Questions posed by the students to solve the murder mystery of the boiler house and the corresponding answers and the student ranking for each question. Question marked with a * denotes the solution to the mystery

#	***Questions posed by the students***	**Answer**	**# upvotes (out of 58)**

1	*What kind of soil material was the boiler room built on?*	Clayey soil	33
2	*What is the type of foundation?*	A raft foundation resting on clayey soil	30
3	*Was the boiler load larger than the safe load?* (students applying structural engineering knowledge of load-bearing)	No, the foundation was over-designed and can safely sustain the load	23
4	*Were there any adverse weather conditions?*	No, but this is an insightful question as students are considering if it is a local site effect or a more global problem	11
5	*Where is the water table?*	the water table is 2 m below the foundation, and the soil voids (pore space) are saturated with water	11
6	***Did the heat from the boiler cause shrinkage in the soil?****	**Yes! Mystery solved!**	**10**
7	*Was the subgrade properly compacted?*	Clayey soil cannot be compacted easily and does not respond to mechanical compaction.	4
8	*Has the clay been treated before with lime?*	No	4
9	*How thick was the foundation?*	The answer was unknown to the author and discussed live during class	3

10	*Could water leak into the soil from the boiler?*	No, the boiler did not leak until the failure	2

Even though the students solved the mystery in just six questions, we did not stop answering the other questions on the online portal. The students posted a total of 30 questions. After solving the mystery in the six questions, I answered nine more questions about the case study. A traditional lecture does not offer the opportunity to explore beyond the bounds of the topic, as it focuses on the linear delivery of content. Advanced topics such as the settlement of foundations, evaluating flooding impacts on foundations, and structural design are only introduced later in the semester or in a different course, limiting the student's ability to link concepts with applications and wrongly promoting knowledge silos.

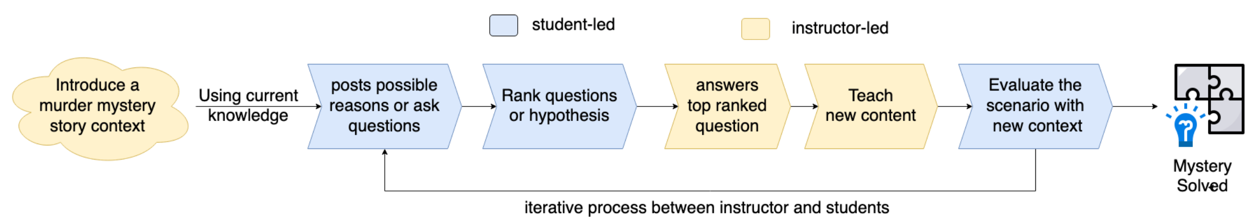


Fig. 2. Murder mystery class structure overview

Figure 2 presents an overview of the murder mystery class structure. Unlike a traditional motivational example, a real-world forensic case history is interwoven throughout the class. Each class begins with a story or a context for the mystery, which includes the site's location, geology, type of structure, and often the socio-economic context. The socio-economic context provides the much-needed and often lacking societal view of how engineering decisions impact our society. For example, in the case of the boiler house mystery, the students discuss the party responsible for the failure, how much compensation should be paid, and by whom. Once the students learn the context, they are encouraged to think of possible reasons for the failure. Their current knowledge and common sense are often sufficient to narrow down potential causes. Online polling tools such as Menti facilitate broader participation among students. The students then collectively brainstorm the possible reasons and prioritize them based on their understanding. The instructor then introduces new concepts or clarifies misconceptions by answering the top-ranked question. When a new concept is introduced, the students build on their current framework of understanding (constructivism) and use their new knowledge to identify another piece of the puzzle. The class is iterative, as each new question from the students is an opportunity to explore new areas and facilitate deeper discussions and understandings. Finally, after several iterations of exploring new concepts, the students acquire all the knowledge to solve the murder mystery. Like typical murder mysteries, this approach also leads to deadends, where students try to explore new ideas and discover that the approach does not work. Engineering decision-making involves a scientific trial-and-error approach where students constantly test their hypotheses. The murder mystery-style teaching encourages having a testable hypothesis and prepares them for the real world. We can also simulate real-world hard choices by restricting the number of questions or limiting their ability to choose between two difficult choices with partial information, as is often the case in engineering.

The murder mysteries help engage the students, increasing the interaction between the instructor and the students. In addition to student-driven discussions, I also take the opportunity to discuss how the engineer in charge went about solving the mystery while emphasizing that it is one of the many possible paths to the solution. While the students focused on finding the answer by asking the least number of questions, an engineer would use her judgment and knowledge to adopt a methodological approach to solving the mystery. It allows me to discuss with the students how to approach a problem systematically. For example, although the first question from the student was to figure out the soil type underneath the foundation, which would require expensive soil sampling and testing, this was the last step taken by the engineer. I discuss how the first step is to do a reconnaissance to determine if the problem is local or site-wide, eliminating potential failure causes such as weather and natural hazards.

The engineer carefully observed the site (shown in Fig 1) – the caving of the room inwards means the soil underneath is shrinking rather than swelling (which causes the walls to bulge out). When the engineer asked to cut through the foundation slab near the door, by the light of the flashlamp, she could see the culprit directly under the concrete slab: **nothing**! Where there should have been compacted rubble, there was a gap so deep that it was only possible to confirm that the rubble did indeed exist somewhere below. As the engineer ruefully withdrew her hand, she took back another clue in the form of a blistered finger. The ground was scorching; a thermometer registered 212 F (100 °C) in the rubble, while the concrete raft was only warm to the touch. Finally, she asked to sink a few small boreholes through the foundation and in the general vicinity, away from the influence of the heat. The first question from the students (what was the soil) was the engineer's last question to prove her hypothesis. The murder mystery approach offers a means to construct new knowledge and helps develop a technique to apply their knowledge in solving real-world mysteries.

The forensic approach also allows the students to explore more complex questions, which are otherwise never discussed in a traditional setting:

- *How should the new boilerhouse be founded?*
- *Would using compact sand under the raft have had the same effect as the compact clay, and if not, why not?*
- And practical questions such as: *How much compensation should the original builder pay?*

The students could discuss these questions on an online discussion board. A traditional engineering lecture does not offer the chance to discuss philosophical and political issues. The engineering profession is not just about handling technical issues but also solving associated societal and political challenges. For example, constructing a dam is not just about creating a sustainable source of water and energy but rather considering the potential dislocation of communities and the environmental impact of wildlife. The lack of consideration of the political and societal needs will result in poorly designed infrastructure that can harm the environment and the public.

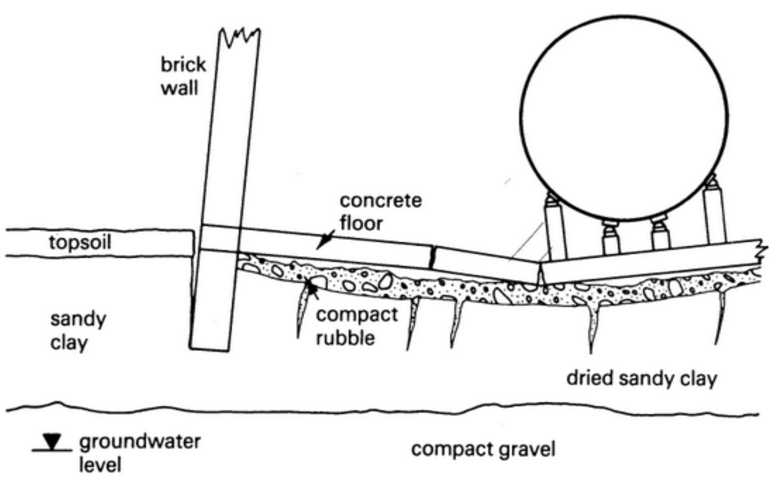


Fig. 2. The case of the collapsed boiler house - mystery revealed (reproduced after [8]).

Students' feedback on learning

During 2021-23, when the course was taught using murder mysteries, it had an overwhelmingly positive response from the students. Forensic-based learning is a compelling student-centered learning model for teaching engineering material behavior and will benefit students across engineering and sciences. The students were not only able to intuitively arrive at the weight-volume relationship but also apply it to other real-world problems. An example discussion board post by one of the students shows their level of understanding of the subject after just one lecture: "*The tennis courts near my house [Austin, TX] tend to crack when the water table rises beneath the asphalt and allowing water to seep into the court, and with repeated seepage or extreme temperatures it can cause fractures and cracks. I think building on an elevated platform and good drainage can reduce cracking.*" This discussion shows the student's ability to identify the problem's source and apply their newly acquired knowledge in proposing possible solutions.

Overall, the course rating improved considerably, achieving the highest in the last twenty years - a rating of 4.9 out of 5.0. Highlights from student feedback: "*the case studies presented in the lectures were a fantastic way to tie in the concepts to their uses in the practical field.*" and "*I think of all my classes, I learned the most in this one. I love telling my friends and family about the interesting case studies we've talked about, and that's all because your teaching style has been really beneficial for me.*" Students enjoy solving puzzles as they feel connected to their future experiences as engineers: "*I please ask you to have some sessions with fellow faculty and teach them your teaching style. It is just amazing and works very well. I always felt interactive during class and understood so much stuff that I don't think would make sense if I just studied on my own*."

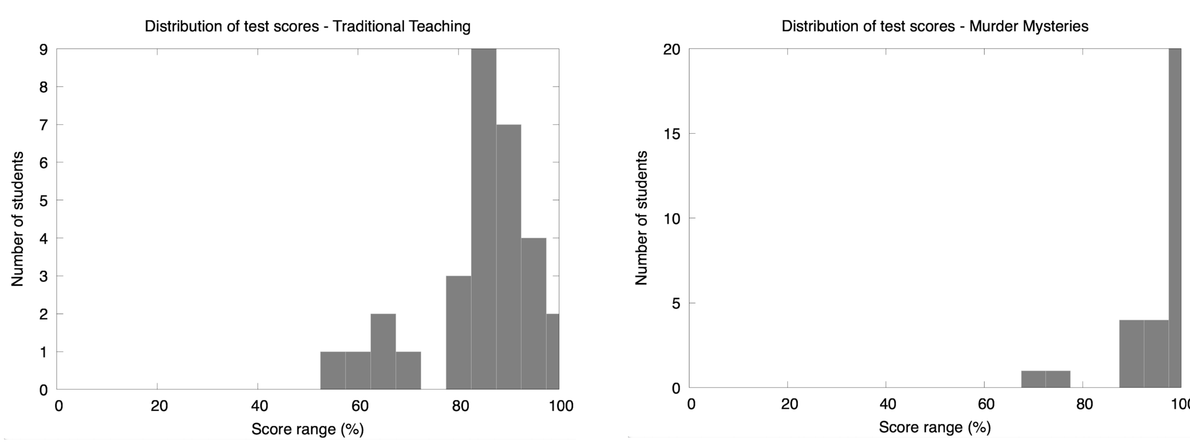
Quantitative assessment of the effectiveness of murder mysteries

We quantitatively compare the effect of murder mysteries on students' learning by evaluating their performance in mid-term exams after traditional and murder mysteries-style teachings. In Spring 2023, we had two instructors teach the Introduction to geotechnical engineering class with 60 students each. The control group was taught traditional lecture-based teaching, while the treatment group experienced murder mysteries. Our initial survey showed that both classes had similar interests in geotechnical engineering. Both classes had the same course content and were examined using the same questions (typical traditional geotechnical engineering questions). Table 2 presents the summary statistics of the performance of both groups.

Table 2: Quantitative comparison of students' exam performance

	Mean	**StdDev**	**Median**	**Highest**	**Lowest**
Traditional teaching	86.57 %	10.86	89.00 %	100.00 %	55.00 %
Murder Mysteries	96.83 %	6.57	100.00 %	100.00 %	74.00 %

We compare the performance of the two groups by performing a T-test and establish a significance of 0.05 for the p-value. The murder mystery-style teaching with 30 participants (*M* = 96.82, *SD* = 6.57) compared to the control group of traditional teaching (M =86.57, SD = 10.86) demonstrated significantly better scores, t=-4.43152 and a p-value of 0.000021. The result is significant at $p < 0.05$. Fig. 4 shows the distribution of scores for both groups. Table 3 presents the projected GPA of the students in both the control and the murder mystery class. More than 79 % of the class will receive an A in the murder mystery-style teaching compared to 49.2%. Also, less than 2 % is projected to receive an F in the murder mystery course, compared to 8.8 % in traditional teaching.



(a) Traditional Teaching

(b) Murder Mysteries Teaching

Fig. 4. Distribution of scores for traditional vs. murder mysteries-style teaching.

Table 3: Projected GPA

	Traditional teaching # (%) of students	Murder Mysteries # (%) of students
A	24 (42.1 %)	51 (79.6 %)
B	17 (29.8 %)	7 (10.9 %)
C	6 (10.5 %)	3 (4.68 %)
D	1 (1.8 %)	2 (3.12 %)
E	3 (5.3 %)	0 (0 %)
F	5 (8.8 %)	1 (1.56 %)

In addition to assessing the overall performance, we also included a critical thinking question. We asked the students to classify the soil based on the liquid and plastic limits and evaluate if the soil was suitable for constructing a flood embankment. The students had to use their knowledge of soil type and behavior to assess if the soil was ideal for construction. Table 4 summarizes the student performance in the critical assessment task. In the murder mysteries course, the students correctly answered the critical knowledge task 86.7% compared to 40% in traditional teaching. The results of the z-test showed that the murder mystery course was significantly more effective than traditional teaching ($z = -3.7506$, $p = .00009$, $p < .05$).

Task 4. Student performance in the critical assessment task

	Mean	**The proportion of students answering correctly (# out of 30)**
Traditional teaching	66.11 %	40.00 % (12/30)
Murder Mysteries	91.11 %	86.67 % (26/30)

Limitations of the current work

Although we used a neutral grader and a predefined rubric to evaluate the performance of the two groups to avoid bias, as the study was conducted in a real-world setting, we cannot avoid instructor bias. The author taught the Murder Mysteries course, while a different instructor taught the traditional lecture-based course but with almost similar teaching experience. The results presented here may be biased by the individual instructor's ability and teaching skills in addition to the teaching mode. A further study using the same instructor teaching in two different modes is required to remove this bias.

Summary and Conclusion

Murder mysteries-style learning provides a coherent, unifying framework to help students structure their knowledge. Students acquire and build knowledge and develop an in-depth understanding of fundamental concepts through solving forensic mysteries. They also learn to problem-solve using engineering, often contributing unique and creative solutions. The murder mystery approach has been successfully applied in the Introduction to Geotechnical Engineering course. It can be adapted to other courses in engineering and sciences, regardless of the teaching mode. This approach creates an active learning environment that encourages student participation. The approach shows a quantitative increase in the course rating (students' likeness to the course) and statistically significant exam performance compared to traditional lecture-based teaching. More research is required to evaluate the teaching approach to avoid instructor bias comprehensively. This work is a preliminary study on the impact of murder mysteries in teaching engineering.

Acknowledgments

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