Session 2023

Preliminary study on teaching an engineering course through murder mysteries

Krishna Kumar
Department of Civil, Architectural and Environmental Engineering
University of Texas at Austin

Abstract

The paper reflects on my teaching of a third-year required undergraduate course, "Introduction to Geotechnical Engineering," through murder mysteries, i.e., forensic case studies-based learning. The murder mysteries involves first introducing an engineering failure relevant to the topic; then the students identify potential reasons for failure and rank them; we then cooperatively explore the different reasons and the students proceed from the known to the unknown and, in doing so, develop a comprehensive understanding of the fundamental principles (abstract concepts) they later encounter. This forensic-based teaching solves the most glaring problem in the traditional method: introducing abstract concepts before presenting concrete examples in the real world. The conventional process inhibits student learning as abstract concepts remain vague and unclear. By introducing an engaging, relevant forensic case study upfront, we capture students' attention and interest and allow them to experience the process of doing real-world engineering. Overall, the course rating improved considerably, achieving the highest in the last twenty years - a rating of 4.9 out of 5.0, well above the average course rating of 3.8 during the same period. The paper describes the background and methodology in developing an engineering course through murder mysteries.

Introduction

In Fall 2021, when I was assigned to teach the Geotechnical Engineering course, a third-year required undergraduate class in Civil Engineering, I was concerned. Students generally perceive this course as challenging, leading many to delay taking it until their final year. And for some, it is the course that stands between them and their dream job. A straw poll of students taking the course in Fall 2020 reflected the above sentiment; less than 12% of the students were interested in learning about Geotechnical Engineering. As students delay taking the course, very few would then continue in the field of geotechnical engineering choosing other more familiar streams of civil engineering. Unlike all the other engineering courses, this is the first time the students will deal with particulate systems (soil) rather than continuum (the more familiar concrete, steel, and water). The course covers fundamental concepts of soil behavior and the students learn how to design foundations and underground structures upon which all civil engineering structures are supported. The course is very demanding, with a lab and an assignment due almost every week. All this contributes to a low average student rating for the course of 3.8/5.0 in the last 20 years, compared to the organization average of 4.1 for the same period. Although student ratings are not an objective metric, and studies have shown bias toward faculty's gender, age, and course grades[1], they provide qualitative feedback, a relative metric, on how much the students liked the course in comparison to other courses. My main concern was to make this course exciting and valuable. As a junior faculty, I was also concerned about the students' perceived lack of interest for the course translating to bad student evaluations influencing my tenure.

In my three years of teaching, all my courses are on abstract subjects like numerical methods and computer programming. Students often find it difficult to learn abstract and complex concepts[2]. Yet, solving critical science and engineering problems require students to learn abstract reasoning. For example, teaching how to solve a system of linear equations is abstract. Although the students may understand the process, they do not understand what the equations represent and what the variables in the equations mean. However, showing how a building deforms under the action of forces provides a concrete example of how the abstract concept of linear equations is used in a real-world structural design. Learning through concrete examples of forces-displacements instead of abstract variables enables the students to apply these concepts to other areas of study. I have realized the importance of grounding abstract concepts in real-world applications. Students appreciate the practical aspects and the links to real-world examples as reflected by student comments such as "*Loved that you used real life examples to teach the material, I learned really well because of the examples*".

In thinking about how to approach the geotechnical engineering course, I hoped to apply some of the strategies of using real-world examples to facilitate deeper student learning. I also wanted to draw on the knowledge gained during a recent teaching fellowship I had that focused on problem-based learning. I had initially planned on using real-world case studies as an introductory but isolated motivational example at the beginning of each lecture. Instead, I decided to restructure the entire geotechnical engineering course around learning new concepts by exploring real-world cases, which naturally led me to examine the idea of Problem-Based Learning (PBL).

PBL involves students divided into smaller groups examining real-world problems with no single or neat solution. In the process of struggling with solving real-world challenges, students "acquire knowledge, content-related skills, self-management skills, attitudes, know-how: in a word, professional wisdom"[3,4,5]. The challenge for me was how to adapt PBL to a large class setting, where the effectiveness of PBL is not well known and remains largely untested[6]. The Introduction to Geotechnical Engineering course has about 70 students per section (~140 students per semester). Adapting the small group interactions to a conventional lecture-based engineering curriculum is impractical due to the lack of additional tutors to facilitate and monitor the cooperative learning phases in a large-class setting.

Murder Mysteries and Teaching Philosophy

Instead of focusing on adapting PBL to a large class setting, I modified the course content and structure by distilling the core idea of PBL using murder mysteries (forensic case histories) to help learners build knowledge through practical problem-solving. First, we introduce an example of an engineering failure relevant to the topic; then the students identify potential reasons for failure; we then cooperatively explore the different reasons where the students proceed from the known to the unknown and, in doing so, develop a comprehensive understanding of the fundamental principles (abstract concepts) they later encounter. This murder mysteries-based teaching solves the most glaring problem in the traditional method: introducing abstract concepts before presenting concrete examples in the real world. The conventional process inhibits student learning, as abstract concepts remain vague and unclear, causing students to lose interest in the subject. By offering an engaging, relevant forensic case study upfront we capture students' attention and interest and allow them to experience the process of doing real-world engineering.

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.

Introduction to 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 this text explains that soil is a three-phase system with soil solids, water, and air, it does not explain why a weight-volume relationship is needed or its significance. More importantly, it completely ignores the fundamental concept that the amount of water in the soil controls its settlement. Without the knowledge of where and why these abstract fundamental concepts are used, the students have a hard time constructing new knowledge without a reference to known information and quickly lose interest in the subject. Let's now explore how I introduce this concept 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.*"

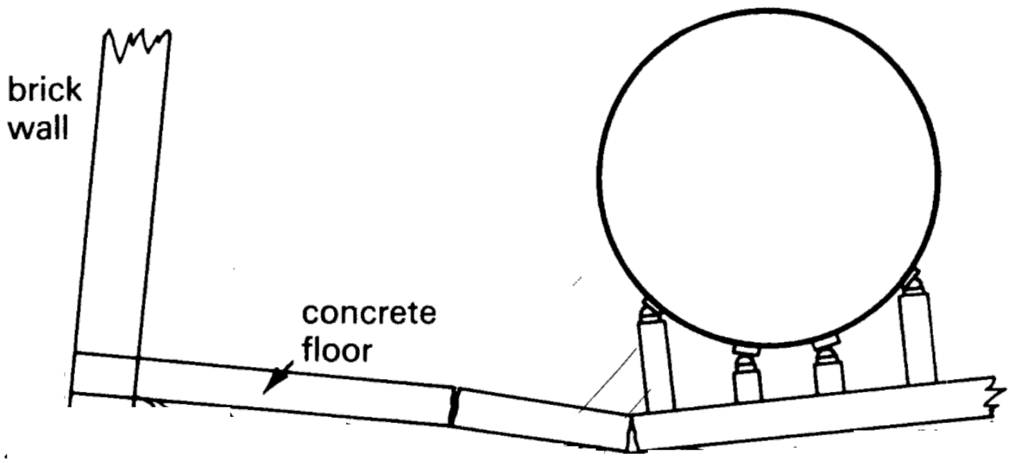

Fig. 1. The mystery of the collapsed boiler house

After the case study is introduced, the students are then 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 the online platform, 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 for the top ranked questions for solving the boiler house murder mystery in Spring 2022 are summarized in Table 1. We see that 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

#	***Question 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, 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 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 the mystery was solved 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 linear delivery of content. Advanced topics such as settlement of foundations, evaluating flooding impacts on foundations, and structural design of a foundation are only introduced in the later in the semester or in a different course, limiting the students' ability to link concepts with applications and wrongly promoting knowledge silos.

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. 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 not only offers a means to construct new knowledge but also helps develop a technique to apply their knowledge in solving real-world mysteries.

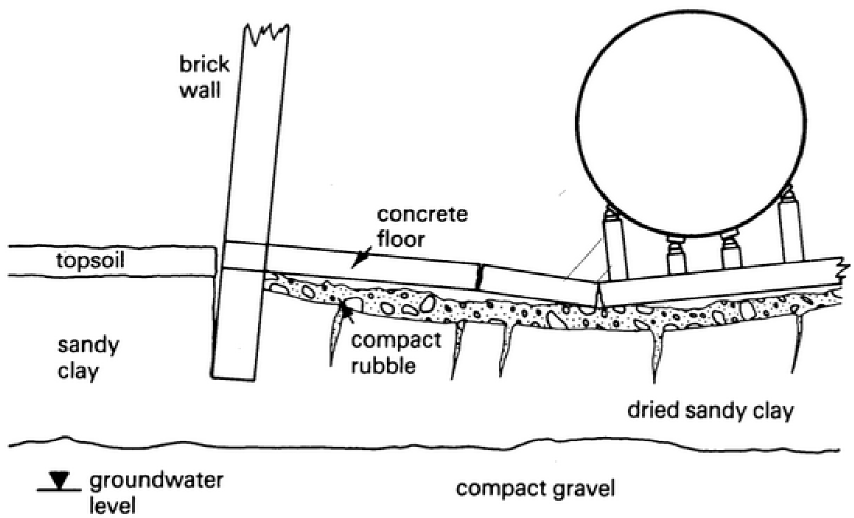

Fig. 2. The case of the collapsed boiler house - mystery revealed (reproduced after Bolton, M.D., 2013).

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 had the opportunity to 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 environmental impact of wildlife. The lack of consideration of the political and societal needs will result in badly designed infrastructure that can harm the environment and the public.

Student feedback on learning

I taught the course through murder mysteries in Fall 2021 and Spring 2022 and 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 not just the ability of the student to identify the source of the problem, but also the ability to 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*."

Summary and Conclusions

Murder mysteries and forensic case histories-based 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 create an engineering approach to problem-solving, often contributing unique and creative solutions to the problems.

The murder mysteries approach explored in the Introduction to Geotechnical Engineering course is not specific to Civil Engineering. It is, in fact, applicable to almost all materials courses in engineering and sciences, which have been traditionally taught in a lecture setting. Murder mysteries are adaptable to other teaching modes: lecture-based, hybrid/remote, asynchronous, and flipped classrooms. Murder mysteries are not just starting from a case study and moving to abstract concepts, it creates an active learning environment for students to explore. Student participation is critical for the success of this approach to teaching engineering.

Murder mysteries-style approach to teaching abstract concepts showed a general increase in participation in the class and the enthusiasm among students (qualitatively evaluated based on the student feedback). The murder mystery approach also showed a quantitative increase in the Course Instructor Survey (4.9) compared to the traditional approach (3.8/5.0). More research is required for a comprehensive evaluation of the teaching approach. This work is a preliminary study on the impact of murder mysteries in teaching engineering.

Acknowledgements

I would like to sincerely thank Dr. Heather Pleasents, Assistant Director for Assessment and Experiential Learning, UT Austin for all the detailed discussions and going above and beyond to offer her immense support in helping me reflecting on the topic and her assistance in writing, reviewing and editing the paper.

References

1. MacNell, L., Driscoll, A., & Hunt, A. N. (2015). What's in a name: Exposing gender bias in student ratings of teaching. Innovative Higher Education, 40(4), 291-303.
2. Demissie, T., Ochonogor, C. E., & Engida, T. (2013). Effects of technology driven pedagogy applications on the comprehension of complex and abstract concepts of chemical equilibrium. African Journal of Chemical Education, 3(2), 57-75.
3. Biggs, J. (1999). What the student does: Teaching for enhanced learning. Higher education research & development, 18(1), 57-75.
4. Biggs, J., & Tang, C. (2011). Teaching for quality learning at university. McGraw-hill education (UK).
5. Savery, J. R. (2015). Overview of problem-based learning: Definitions and distinctions. Essential readings in problem-based learning: Exploring and extending the legacy of Howard S. Barrows, 9(2), 5-15.
6. Pastirik, P. J. (2006). Using problem-based learning in a large classroom. Nurse education in practice, 6(5), 261-267.
7. Das, B. M. (2021). Principles of geotechnical engineering. Cengage learning.

KRISHNA KUMAR
Dr. Krishna Kumar currently serves as an Assistant Professor in the Department of Civil, Architecture and Environmental Engineering at the University of Texas at Austin. His research interests include differentiable programming, explainable AI, numerical modeling and natural hazards.