

Teaching Geotechnical Engineering through ‘Murder Mystery’ Problem-Solving

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ABSTRACT

Engineering courses taught in traditional lecture-based format are often perceived as difficult by students as they struggle to understand the concepts and perform well on the assessments. Attempts made to address these issues by using innovative active-learning methods have shown promising outcomes, yet limited institutional resources and the lack of familiarity with alternative pedagogies impose limitations on the scalability and acceptance of these innovations. To overcome these challenges, this study investigates the potential of partial incorporation of problem-based learning (PBL) methods using case-studies of real-world engineering failures in a large geotechnical engineering course. It adopted a quasi-experimental and repeated measure design to compare both learning and attitudinal outcomes between students in two different sections of the course – one section utilized the traditional lecture-based methods (the comparison group), and the other section utilized case-studies as the primary pedagogical approach (referred to as the “Murder Mystery” approach). Quantitative analysis demonstrated the comparative advantage of using the Murder Mystery approach over the traditional lecture-based teaching methods on both cognitive and affective student learning outcomes. Results show that, as compared to students in the comparison section, students taught using the Murder Mystery approach performed significantly better on

the final exams. Additionally, they perceived the course to be relatively less difficult by the end of the semester, retained interest in the subject over the course of the semester, and also increased their confidence. Introducing elements of active-learning methods, like PBL and case-studies, in otherwise instructor-centered classes is thus recommended to improve students' overall engineering learning experience and the conceptual understanding.

AUTHOR KEYWORDS (OPTIONAL): Problem-based learning (PBL), Forensic case-histories, Interest, Confidence, Geotechnical engineering

INTRODUCTION

Overview

Innovations in engineering education are a continued priority for the field. Research has shown that traditional teaching methods are often not aligned with the needs of the profession. Traditionally, instructors have focused on transmitting facts and theories but not on providing enough opportunities for developing skills required to excel in the complex, real-world, team-based environments. To overcome these limitations engineering educators are increasingly adopting more learner-centered pedagogies, such as Problem-Based Learning (PBL), which can have positive effects on students' learning outcomes (Cleary 2020; Gross & Musselman 2018; Ling & Gan 2020; Yehia & Gunn 2018; Zhang 2023). Yet fully implementing PBL in engineering classrooms can prove difficult, due to logistic issues (e.g. large class sizes, time and resources needed to re-design classes), fear of student resistance, and concerns about content coverage by the faculty (Borda et al. 2020; Chen et al. 2021; Mojtahedi et al. 2020).

One way to help address these issues is to incorporate elements of innovative pedagogies in traditional courses instead of aiming to completely redesign courses. This article explores the benefits of a course design that incorporates aspects of PBL, while still overall utilizing a primarily instructor-centered classroom approach. Specifically, the focus is on a geotechnical engineering course section that incorporated forensic case histories to examine whether such a format increased students' learning, as well as their interest and confidence in engineering, relative to students in the traditional, lecture-based section.

Problem-Based Learning in Engineering Courses

Initial development of problem-based curricula in the 1960s was motivated by issues similar to those prevalent in engineering education today. These include students' disinterest in content, low retention of concepts, and little perceived relevance of the curriculum to professional environments (Barrows 1996). Central to PBL is the use of problems as a part of instruction; according to Hmelo-Silver (2004), a good problem is complex, ill-structured, open-ended, realistic, relatable, and requires students to gather information from diverse resources. PBL classes are learner-centered wherein students often work collaboratively in small groups to examine the problem, analyze data and generate hypotheses for potential

causes or solutions, while the instructor scaffolds problem-solving by asking questions and models good learning and reasoning strategies. As such, PBL is meant to promote the development of problem-solving skills and elaboration of knowledge, and increase engagement and motivation for learning (Barrows 1986, 1996; Hmelo-Silver 2004).

Several researchers have examined the benefits of fully implementing problem-based learning in engineering courses, either by developing a new course or by completely re-designing an existing course. For example, El-adaway et al. (2015) developed a new course to integrate the concepts of sustainability and infrastructure development, whereas de Justo & Delgado (2015) introduced PBL techniques in a structural engineering course. Both of these studies showed positive effects of engagement in PBL methods on students' cognitive learning outcomes. El-adaway et al. (2015) found that students' performance on course assessments improved overtime throughout the semester, reflecting gains in knowledge, comprehension, application, analysis, synthesis, and evaluation skills. PBL courses have also been shown to have a positive influence on students' self-perception of learning (El-adaway et al. 2015; de Justo and Delgado 2015).

While quantitative studies in engineering education have focused largely on measuring cognitive outcomes, qualitative studies have investigated students' attitudes towards PBL-based courses. Du et al. (2022) found that students in two problem-based learning civil engineering courses developed a stronger sense of identity as a professional engineer and increased their motivation. Similarly, Servant-Miklos & Kolmos (2022) found that participants enrolled in various engineering courses like mechanical, electronics, and environmental planning etc., perceived PBL as an opportunity to explore their engineering identity by enabling self-reflection and personal development, leading to a growth in self-confidence. Other studies have used course evaluations and metrics such as increased attendance rates and decreased dropout rates as indirect measures of impact on student motivation (de Justo and Delgado 2015).

Potential Limits of Full PBL and Affordances of Partial Implementation of PBL

The positive outcomes documented from the use of PBL in engineering classes notwithstanding, both obstacles and concerns to full implementation exist. Chen et al. (2021) provide a comprehensive review of the individual, institutional, and cultural level challenges encountered in PBL implementation,

including increased human resources (e.g., in the form of the number of facilitators required to guide students) and financial support. Relatedly, several researchers have asserted that problem-based learning is only suitable for small class sizes (de Justo and Delgado 2015; Solís et al. 2012). Beyond these logistical issues, student discomfort with PBL given its relative rarity in their educational experiences overall is also a concern. For example, a study of electrical engineering courses by Yadav et al. (2011) found that compared to classes using PBL, students expressed feeling more comfortable with the traditional teaching methods with which they were more familiar, even though analysis of pre-post tests revealed they developed more conceptual understanding in PBL classes. Additionally, team-based PBL environments have been perceived as “emotionally unsupportive” and even “hostile” by neurodivergent students (Servant-Miklos and Kolmos 2022). Collectively, these studies suggest that cognitive learning outcomes may not always be accompanied with positive attitudinal shifts, and it is therefore important to give equal weight to cognitive and affective outcomes when evaluating a new pedagogical approach.

To improve the teaching-learning experience in their courses, some engineering instructors have also used a unit-based design or a combination of traditional and problem-based methods throughout the course. Scholars have argued that the benefits of partial implementation include requiring fewer resources to innovate teaching practices and also creating less of an abrupt departure for students from their usual learning experiences (Striolo et al. 2021). Importantly, similar to the whole unit design, studies on partial PBL implementation have found positive effects on cognitive learning outcomes evidenced by factors like increases in exam scores, increases in course passing rates, better retention of course concepts, and building of a sense of autonomy in the problem solving process (Solís et al. 2012; McWhirter & Shealy 2018; Rodrigues Da Silva et al. 2012).

Research on the impact of partial PBL designs on affective learning outcomes, such as positive attitudes towards engineering, is more limited. For example, while McWhirter & Shealy (2018) reported an increase in student confidence, a comparative study by Yadav et al. (2011) found that traditional teaching methods were more successful in fostering students’ confidence in their understanding. Some studies did not explicitly measure affective outcomes, yet the researchers stated that they observed an increase in

students' interest in the subject and in problem solving while teaching the course using PBL (Solís et al., 2012; Rodrigues Da Silva et al., 2012).

Incorporating Case Studies within PBL in Engineering Courses

Real world issues, events, or examples are often used as a central element in classroom innovations, developed into 'cases' to better engage students and make learning more relevant to their careers (Richards et al 1995). In engineering education, cases may provide an account of a problem, technical or business issue, or design challenge, and may be used to simulate a variety of design and analysis experiences. Cases are usually derived from actual experience and reflect "real-world" concerns of managers and professionals. Not surprisingly, there is evidence that designing PBL courses around real-world problems has produced significant cognitive and affective learning gains in engineering courses (Du et al. 2022; Halpin et al. 2004; de Justo and Delgado 2015; McWhirter and Shealy 2018; Yadav et al. 2019). For example, Halpin et al. (2004) used multimedia case-studies focusing on real-world problems and solutions in an introductory engineering course designed as PBL and offered to pre-engineering students. Their analyses revealed improvement in students' self-perceived ability to deal with engineering problems, communication skills, and confidence in expressing ideas. Moreover, compared to students in a traditional class, those in the PBL course earned higher grades and were subsequently admitted to professional engineering courses in greater numbers. Similarly, Pucha & Utschig (2012) observed that students who worked on case-based problems were more engaged in the course and outperformed their peers in final course exams, despite feeling that they learned less as compared to the traditional settings.

Forensic case histories represent a subset of case studies that are particularly suited to civil engineering. Stimson (2018) explains "Forensic analysis is the application of scientific principles to the investigation of materials, products, structures, or components that fail or do not function as intended (p. 2)". In civil engineering education, forensic case histories support investigation of actual engineering failures and serve as a valuable source from which to derive complex real-world problems. As students study the failure cases, they are challenged with questions about the causes of the failures and how to prevent similar events in the future. Delatte & Rens (2002) encourage integrating failure case studies in

traditional civil engineering courses to “illustrate key technical principles” and “offer valuable insights into associated technical, ethical, and professional issues”. Furthermore, Delatte (2008) underscores the potential of “failure literacy” in fostering learning in affective, cognitive, and social domains. He argues that case-studies can increase interest in learning and motivate students to retain knowledge while exposing them to the social and communal impacts of engineering decisions. Delatte et al. (2009) assessed the impact of failure case studies in engineering mechanics and civil engineering courses and found that students reported positive perceived learning outcomes with respect to application of knowledge to real-life situations, problem-solving skills, and knowledge of contemporary issues. Additionally, they found that failure case studies had the largest contribution in making the course more interesting for students in comparison to other course elements like lectures, exams, and projects.

MOTIVATION AND OBJECTIVES

There is promising evidence that real-world problems, presented in the form of forensic case studies within a problem-based learning environment, might be particularly suited to increasing student engagement and learning in civil engineering courses. Yet there are clear challenges in fully implementing PBL in large engineering courses, including logistics as well as concerns with student discomfort. This study aims to examine if integrating forensic case histories, using some of the core principles of PBL, into a mostly teacher-centered geotechnical engineering course, can lead to increased student learning and more positive affective outcomes, including interest and confidence in geotechnical engineering.

Course Description

Introduction to Geotechnical Engineering is a required third-year undergraduate course at the University of Texas at Austin in civil engineering that covers fundamental concepts of soil behavior and the design of foundations and underground structures. Traditionally, students have perceived this course as challenging, often delaying it until their final year. The content involves dealing with particulate systems (soil) rather than continuum materials like concrete or steel, which is unfamiliar to most students at this stage. Correspondingly, course ratings on student evaluations (before the intervention described

below) averaged around 3.8 on a scale from 1 (low) to 5 (high), notably lower than the average course rating of 4.25 in the department of civil engineering.

Recognizing students' reluctance and aiming to make the course more engaging, the instructor (and second author) of one of the two course sections designed his classes using forensic case histories, an approach that the students referred to as “Murder Mystery” in connection to the board game Clue/Cluedo. Rather than beginning with abstract concepts, each class starts with a real-world engineering failure relevant to the topic. Students collaboratively explore potential reasons for the failure, building their understanding of fundamental principles as they work to solve the mystery. This approach grounds abstract concepts in practical applications, allowing students to experience the process of real-world engineering problem-solving. The other section, which serves as the comparison group, covered the same topics and labs in an asynchronous lecture-based format.

The Murder Mystery section maintained the same content coverage as the traditional version but integrated it within 15 forensic case history analyses as listed in Table 1, covering topics from soil classification to consolidation and shear strength. A new forensic case was introduced each week, aligned to that week's topic, and interleave just-in-time theory with the top-ranked student questions. The first case (Collapsed Boiler House) appeared in Week 1, Lesson 1 within the first five minutes of class. The next sub-section provides a detailed description of the first case, while brief summaries of three additional case studies appear in Appendix I.

The total class time (approximately 75 minutes) was divided as follows: 5–10% for case framing, about 20% for student question generation & ranking, 25–30% for targeted concept exposition (interwoven with Q&A), 30–35% for guided solutioning, 5–10% for professional/ethical reflection, and 5% for wrap/exit check. For a 50-minute period, all lesson segments were proportionately time-boxed (see Appendix II) - inquiry (≈ 10 min), concept inserts (≈ 12 – 15 min), guided solutioning (≈ 18 – 20 min), and reflection (≈ 3 – 5 min).

Illustrative Case History: The Case of the Collapsed Boiler House

"The Case of the Collapsed Boiler House" (Fig. 1) is strategically introduced early in the semester to establish tangible connections between abstract soil mechanics principles—particularly weight-volume relationships—and real-world engineering applications before engaging in formal theoretical development. By grounding these concepts in an authentic failure scenario, the intent is that students immediately recognize the practical significance of the technical material they will subsequently master.

The case narrative begins with a compelling engineering failure. In 2021, new ownership of a whole foods firm invested over \$900,000 in expansion and modernization efforts, allocating \$400,000 specifically for a new boiler house near Houston, Texas. This critical facility served dual purposes: supplying pressurized steam to a food processing plant and central heating for the factory complex. Within weeks of achieving full operational capacity, the structure exhibited alarming symptoms. Windows inexplicably shattered. Significant cracks appeared and rapidly propagated throughout the concrete floor slab. Despite the local builder's remediation attempts, conditions worsened dramatically, culminating in a hazardous steam burst that scalded two technicians in the food processing unit. By January 2022, merely six months after commissioning, the situation had deteriorated to the point where operations ceased entirely. The structural walls displayed pronounced inward rotation—a telltale sign of foundation instability. The roof developed significant leaks. Most concerning, the massive boiler visibly subsided, settling approximately 100 mm from its original position atop an extensively damaged floor slab. Facing mounting financial pressure as their modernization loan repayment hinged on resuming full production, and having lost confidence in the builder's remedial capabilities, the owners sought specialized consultation from a geotechnical engineering firm.

Instructional methodology

The pedagogical approach employed for this study deliberately simulates authentic professional engineering practice within the classroom environment. Rather than fragmenting students into small groups, the entire class acts as a unified consulting entity investigating the failure. This collective approach is intended to foster comprehensive engagement and model collaborative problem-solving in a large class setting (~75 students). To introduce realistic constraints, there is a simulated budget

mechanism. The class initially determines an appropriate consulting fee for resolving the engineering mystery, which becomes their resource allocation. This budget serves as the financial constraint governing their investigation, requiring strategic decision-making about information-gathering priorities.

In a large-enrollment class (typically >60 in-person with several on Zoom), engagement was operationalized via an anonymous online polling platform (Menti). Each lesson included four interactions: (i) student-generated investigative questions, (ii) peer-ranking to prioritize, (iii) brief concept polls, and (iv) an exit reflection. Participation was incentivized—not graded—through a 10-question class budget: if students resolved the case in fewer than 10 questions, each unused question converted to homework time-bank hours (e.g., four unused questions → eight hours of extension). With this design and phone-based access, >95% of enrolled students participated in most activities. Menti preserved anonymity among peers; the instructor monitored unique participation counts but did not link responses to the gradebook.

This anonymity is intended to encourage participation from all students regardless of confidence level and promote inclusive inquiry. Following question generation, students collectively rank the submissions, democratically determining the highest-priority line of investigation. Resource constraints directly influence this prioritization process. Each top-ranked question incurs a predetermined cost deducted from the class budget. Upon "purchasing" a question, the instructor provides information drawn directly from the original case documentation. For instance, if students prioritize "What is the underlying soil type?" (see Table 2), the instructor would reveal that the subgrade consists of clayey soil.

Students are prompted to pose evidence-seeking questions (what observation or datum would confirm/deny) rather than unsupported claims. After the students vote on questions, the instructor then inserts compact theory segments related to the top-ranked questions. If a valuable question lacks an immediately supported answer, the students may 'purchase' the datum if feasible within the class budget; otherwise, the instructor assigns a short relevant reading for the next class, or revisits the questions once the relevant fundamentals have been introduced.

This process—question submission, ranking, expenditure, and instructor response—proceeds iteratively. As new information emerges, students reassess their hypotheses, refine their questions, and strategically allocate their remaining resources. The goal is for students to engage in systematic information gathering, hypothesis testing, and efficient problem-solving. Effective resource management is incentivized by converting any remaining budget into a "time bank" applicable to future assignment deadlines, rewarding focused and efficient investigation. As the investigation advances through multiple inquiry cycles, students typically eliminate obvious structural deficiencies and common external factors as potential causes. Guided by factual responses from the actual forensic report, the class gradually narrows its focus toward subtle interactions between the structure, its operational environment, and the geotechnical conditions.

Once students establish that conventional issues like foundation overloading are not causative, their inquiries invariably shift toward environmental influences on the clay subgrade. Questions regarding groundwater levels or thermal effects from the boiler typically emerge as high priorities. The pivotal breakthrough occurs when students discover that significant heat transfer from boiler operations caused soil desiccation and consequent shrinkage in the underlying clay—the fundamental mechanism behind the observed failure. This qualitative determination necessitates quantitative validation, mirroring standard engineering practice. At this juncture, the instructor formally introduces weight-volume relationships in soil mechanics, guiding students through measuring moisture content in the lab and eventually doing a back-of-the-envelope estimate of the potential settlement attributable to clay drying. Using documented data (initial moisture content of 18.5%) and standard geotechnical parameters (initial saturation of 1.00, specific gravity of 2.70), students calculate an initial void ratio of 0.50 using the relationship:

$$wG_s = Se \quad (1)$$

The analysis then addresses conditions in clay directly affected by boiler heat, where moisture content dropped dramatically to 3.1%. Here the instructor introduces the concept of desiccation limits in fine-grained clayey soils, explaining that while moisture loss causes shrinkage, physical constraints limit volume reduction. For desiccation settlement, students must justify a plausible void ratio prior to

calculation. We scaffold with a typical range for dried clays ($e \approx 0.35\text{--}0.45$) and standard assumptions on S_r and G_s , illustrating why very low e is unrealistic; students then recompute after learning the clay-shrinkage mechanism and constraints. Adopting a plausible final void ratio of 0.41 (within typical ranges for desiccated clays), students estimate vertical settlement using the one-dimensional consolidation formula:

$$\Delta H = H_{\text{initial}} \times \frac{\Delta e}{1 + e_{\text{initial}}} \quad (2)$$

With a 2.0 m affected clay layer, this calculation yields approximately 0.12 m of settlement—closely matching the observed minimum settlement of 0.10 m and confirming heat-induced desiccation as the primary failure mechanism.

Professional and ethical dimensions

The technical diagnosis serves as a gateway to broader professional discussions. After resolving the engineering mystery, students are encouraged to engage with questions of accountability: Did responsibility rest with the design engineer who potentially overlooked thermal effects, the contractor responsible for installation, or the owner regarding operational factors? These complex considerations introduce future professionals to concepts of liability, the critical importance of comprehensive site characterization, and the interconnected nature of various engineering roles. The discussion extends to evaluating remedial strategies, comparing options such as complete reconstruction with improved thermal isolation versus salvaging the existing structure through specialized techniques like underpinning or void grouting. Students can weigh technical feasibility against cost implications and operational disruptions. Further exploration of appropriate compensation structures and consulting fee bases for remediation design can encourage engagement with engineering practice's economic and contractual realities. The narrative arc—from initial problem presentation through methodical investigation to solution development—provides a microcosm of authentic engineering practice, is intended to prepare students for the complex challenges they will encounter in their professional careers.

DATA AND METHODS

With the approval of the Institutional Review Board (IRB) of the university, the data for this study was collected in Spring 2023 from two sections. One section was the re-designed course just described, hereafter referred to as the Murder Mystery (MM) section, taught using problem-based learning methods employing forensic case histories of real-world engineering failures. Another section of the same course taught using traditional lecture-based teaching methods served as the comparison. Data on students' engineering attitudes and their learning experience was collected through surveys using Qualtrics, an online survey tool. Pre-surveys were collected by the research team at the beginning of the semester on the first day of the class, and post-surveys were administered at the end of the semester, a week before the final exams. Approximately 70% of all enrolled students across both sections (n=93) completed questions about their background and their engineering attitudes (described below). At the end of the semester, 70 students across both sections completed the post-survey, most of whom had also completed the Beginning of Semester survey (n=64). Both pre-survey and post-survey respondents were roughly equally divided between the Murder Mystery section and the comparison section (see Table 3).

The pre-surveys also collected information on students' background characteristics including gender, race and ethnicity, first-generation status (first in their family to attend college), mother's education level, and year in college. Table 3 displays the distribution of student characteristics separately for each section. Analysis using Fisher's exact test of independence revealed that the two course sections were similar in terms of the distribution of student characteristics (e.g. no statistically significant differences).

The research team compared the two course sections on the following outcomes, all measured via surveys: change over time in attitudes (confidence and interest in geotechnical engineering), change over time in perceived course difficulty, and perceived learning at the end of the semester (both cognitive and affective dimensions of learning). Students' exam scores were also compared. Mixed-design ANOVA were conducted to analyze whether there was a change in students' attitudes and perceived course difficulty over the semester and if this change differed between the two course sections. Independent sample t-tests were

conducted to examine differences between the two sections in perceptions of learning and exam scores, both measured once at the end of the semester.

Student Attitudes: Confidence and Interest in Geotechnical Engineering

To measure students' interest and confidence in geotechnical engineering, survey items from previous studies of engineering education were revised (Patrick et al. 2021), adding the word 'geotechnical' in each item. Specifically, confidence was measured with two items on both the pre-survey and the post-survey: (a) "I am confident that I can understand concepts in geotechnical engineering" and (b) "I can do well on exams in geotechnical engineering." Calculation of Cronbach's alpha revealed a satisfactory fit ($\alpha = 0.74$), and students' responses were averaged across both items. Students' interest at both the beginning and end of the semester was captured with the following four items: (a) "I think I will enjoy learning geotechnical engineering", (b) "I am interested in learning more about geotechnical engineering", (c) "I am interested in going to graduate school to study geotechnical engineering", (d) "I am interested in a job or occupation in geotechnical engineering." Again, items were averaged to form a scale ($\alpha = 0.78$). Response categories for all individual items captured level of agreement on a 5-point Likert scale ranging from "Strongly Disagree" (1) to "Strongly Agree" (5). Therefore, higher scores on both scales indicate more positive attitudes towards geotechnical engineering (e.g. higher confidence or higher interest). Results of t-tests confirmed that at the beginning of the semester, the two sections were comparable in terms of students' interest and confidence in geotechnical engineering. Specifically, the average confidence level at time 1 for the MM section ($M=3.62$, $SD=0.56$) and the comparison section ($M=3.74$, $SD=0.55$) were not statistically different, $t(91) = -1.02$, $p=0.31$. Similarly, the difference in mean scores on the interest scale for the MM ($M=2.98$, $SD=0.64$) and the comparison ($M=2.90$, $SD=0.71$) sections was also not statistically significant, $t(91) = 0.58$, $p=0.56$.

Students' Perceptions of Learning

Three different measures capture students' perception of learning. The first is a single item that asked students to rate their perceptions of the course difficulty on a scale from 1 (extremely easy) to 5

(extremely difficult). This question was asked on both the pre-survey and post-survey, providing the opportunity to examine change over time for each section. At the beginning of the semester, the expected levels of course difficulty reported by the MM ($M=3.60$, $SD=0.69$) and the comparison ($M = 3.62$, $SD = 0.67$) sections were not significantly different, $t(91) = -0.18$, $p = 0.86$.

Two additional measures capture students' self-perceived learning over the course of the semester, and were therefore only included on the post-survey. These items were adapted from studies that examined students' perceptions of their learning in STEM classes where active learning methods and case-studies were used (Deslauriers et al. 2019; Yadav et al. 2010). Students indicated their level of agreement with each statement on a 5-point Likert scale. The cognitive learning scale ($\alpha = 0.74$) was composed of statements that directly addressed course content or concept learning, e.g., "The instruction in this class helped me in learning the course concepts". The other scale ($\alpha = 0.72$) captured more affective measures of learning, such as enjoyment and engagement in the class. See Appendix III for the complete list of questions.

Final Exam Scores

In addition to students' perceptions of learning, analysis examined their mastery of the course content as indicated by their exam scores. The comprehensive final exam was designed to be consistent with regular class assessments (e.g. it did not include any questions specific to the case studies in the Murder Mystery class). Additionally, as it included open-ended questions, it was graded by neutral evaluators who did not know in which section students were enrolled.

RESULTS

Confidence in Geotechnical Engineering

The results of the mixed design ANOVA (see Table 4) revealed a statistically significant interaction effect between section and time ($F(1,62) = 4.40$, $p < 0.05$, $\eta^2 = 0.07$), indicating that the main effect of time differed between sections. Post-hoc analysis examining simple main effects (change over time for each course section) revealed that the average confidence of students in the MM section increased over the course of the semester, from the pre-survey ($M = 3.58$, $SD = 0.48$) to the post-survey ($M = 4.05$, $SD = 0.41$), and

the change was statistically significant ($p < 0.001$). The magnitude of the increase was substantial (Cohen's $d = 0.66$). However, there was no statistically significant change in confidence for students in the comparison section ($p = 0.77$). Fig. 2 visually displays these results.

Interest In Geotechnical Engineering

Results from a mixed-design ANOVA predicting student interest also indicated a statistically significant interaction effect between course section and time, $F(1,62) = 5.86, p < 0.05, \eta^2 = 0.09$. In this case, post-hoc analysis revealed that for the comparison group, there was a statistically significant decrease ($p < 0.05$, Cohen's $d = 0.39$) in students' interest in geotechnical engineering over time. Specifically, while students in the comparison section began the semester indicating that on average their level of interest was neutral ($M = 3.01, SD = 0.70$), this decreased such that they slightly disagreed that they were interested in geotechnical engineering at the end of the semester ($M = 2.70, SD = 0.84$). In contrast, for students in the MM course section, their level of interest did not show a statistically significant change over time ($p = 0.24$), such that they maintained the same level of interest over the course of the semester (see Fig. 3).

Perceived Course Difficulty

Turning to perceived course difficulty, we once again observed a statistically significant interaction effect between section and time, $F(1,60) = 6.63, p < 0.05, \eta^2 = 0.10$. Post-hoc calculation of simple main effects revealed that the average perceived difficulty of the course content decreased over time for students in the MM section and this change was statistically significant (Pre-survey $M = 3.65, SD = 0.61$; Post-survey $M = 2.87, SD = 0.62, p < 0.001$). The effect size was very large, at almost one standard deviation (Cohen's $d = 0.96$). For students in the comparison section, although perceived difficulty also appeared to decrease slightly over the course of the semester, this difference was not statistically significant at the conventional level ($p = 0.07$). See Fig. 4.

Self-Perceived Learning

Self-perceived learning was measured on the post-survey at the end of the semester. Overall, the average learning experience in both sections appears positive as the mean response value was greater than 3 (neutral) for all questions. However, the means for the MM section were higher on scales measuring the

affective aspects and the cognitive aspects of learning, and the differences between the two sections were statistically significant on both the scales. Specifically, t-tests revealed that students in the MM section ($M = 4.14$, $SD = 0.45$) had a stronger affective learning experience than students in the comparison section ($M = 3.64$, $SD = 0.55$), $t(68) = 4.10$, $p < 0.001$. The same was true for perceived cognitive learning outcomes, where students from MM section ($M = 4.26$, $SD = 0.40$) rated their learning experience higher than students in the comparison section ($M = 3.90$, $SD = 0.60$), $t(68) = 2.87$, $p < 0.01$. The effect size was very large for the affective learning scale (Cohen's $d = 0.98$) and moderately large for the cognitive learning scale (Cohen's $d = 0.69$). See Fig. 5.

Exam Scores

In addition to perceived learning, final exam scores were also compared between sections. Students in the MM section ($n = 64$, $M = 92.66$, $SD = 7.72$) on average outperformed students in the comparison section ($n = 58$, $M = 82.6$, $SD = 12.2$), $t(120) = -5.41$, $p < 0.001$, with statistically significant difference in mean scores and a very large effect size (Cohen's $d = 0.985$).

DISCUSSION

This study examined how incorporating real world engineering case-studies in the pedagogy of a teacher-centered geotechnical engineering class can improve students' learning experience and assessment outcomes. The in-depth analysis presented is an important contribution to the existing literature because positive results on one indicator (e.g. cognitive learning outcomes) do not automatically imply success on others (e.g. attitudes).

The results indicate that the Murder Mystery approach was effective in increasing students' confidence in their geotechnical engineering learning ability and performance. Such positive attitudinal outcomes are important because previous research has established the importance of self-efficacy in predicting achievement and persistence in scientific/technical majors, even net of students' prior academic experiences and background (Lent et al. 1986). The Murder Mystery approach also appeared to prevent a decline in students' interest in geotechnical engineering over the course of semester, in contrast to the significant decline observed in the section taught using traditional methods. Decline in learning interest as

students progress in their program has also been overserved in prior international research on undergraduate students in engineering and technology (Alpay et al. 2008; Savage et al. 2011). The results of this study suggest that perhaps partial implementation of problem-based learning techniques incorporating real world case studies can be an effective way of retaining interest in learning engineering and in engineering careers.

FACULTY PERSPECTIVE

From an instructor's perspective, the primary concern before implementing the Murder Mystery approach was whether dedicating significant class time to exploring these "Murder Mysteries" would compromise the breadth of theoretical content covered. Would there be sufficient time for the fundamentals? The surprising yet powerful realization was that forensic case histories offer a practical and intrinsic way to teach the fundamentals. By presenting students with a tangible problem first - a collapsed structure, a failing dam - instead of leading with abstract theory, the mystery itself created the need to understand the underlying principles (see Fig. 6. for a 'before vs. after' illustration of the lesson structure). This shift appears crucial for engagement and comprehension in these foundational courses. Investigating the failure, asking questions, and piecing together the evidence appeared to drive students to learn and apply the necessary concepts—phase relationships, soil classification, or seepage principles.

Other potential deterrents to adapting this approach include the considerable upfront effort required in selecting and preparing case studies as well as the demand from the instructors to be adaptable facilitators comfortable with student-led inquiry. Therefore, optimizing regular lesson planning is crucial for effective course delivery. In this study, the instructor of the Murder Mystery course section capped the preparation time at 6 hours/week (two sessions/week). These prep sessions were used to source the cases, simplify multifactor failures, prepare typed narrative notes, and build Menti assets. Since many artifacts are reusable, subsequent offerings require substantially less time and efforts. Other recommendations for future improvements based on the instructor's experience of implementing the "Murder Mystery" approach are as follows:

- Start with one high-signal case that naturally reveals a core concept (e.g., Collapsed Boiler House for weight–volume relationships in Week 1).

- Use anonymous question submission + ranking; track unique participation counts to quantify engagement.
- Time-box inquiry (~10–12 min questions, ~5 min ranking) to protect solutioning time.
- Interleave just-in-time theory exactly where student questions demand it.
- Maintain a small question bank per case to address likely detours and to ‘park’ off-path questions.
- Close with a brief professional/ethical reflection tied to consequences.
- Leverage a class Discord channel for students to post local failures; award small bonus points for high-quality sightings and explanations.
- If preparation time is scarce, pilot with two cases and reuse the same Menti workflow.

LIMITATIONS

While the results of this study underscore the potential of partial transformations towards problem-based learning teaching methods in engineering as a way of improving attitudes and learning outcomes, it is not without limitations. First, the study design is not truly experimental, as the instructors were different across sections, and students were not randomly assigned (although see Table 3 regarding similarities in student characteristics). Second, the relatively small sample size did not permit the opportunity to look for potential differences in impact of the course by student characteristics, such as race, gender, or first-generation status. Classroom observations and student interviews could also have provided more detail and context of students’ experiences.

CONCLUSIONS

The experience of implementing and evaluating the Murder Mystery approach in a geotechnical engineering course section offers significant insights, particularly for teaching subjects often perceived by students as abstract and challenging. Introduction to Geotechnical Engineering is a cornerstone of the civil engineering curriculum, laying the groundwork for understanding how structures interact with the earth. Yet, its departure from familiar continuum mechanics and its inherent complexities frequently lead to student apprehension and disinterest, potentially steering them away from a critical specialization.

Implementing the Murder Mystery approach, centered on forensic case histories of real-world failures, seems transformative. The positive outcomes observed in this study—particularly the boost in student confidence, the prevention of declining interest, lower perceived difficulty, and improved exam scores, all relative to the comparison course utilizing a traditional lecture format—strongly imply that grounding abstract concepts in compelling, real-world problems can significantly enhance both the learning experience and student success in vital engineering gateway courses.

A central lesson learned during this process revolved around the efficiency and effectiveness of the case-study method itself. It fosters the ability to approach complex problems systematically, a skill far more valuable than rote memorization, truly preparing students for the challenges they will face as practicing engineers. The "Mystery" embedded in a forensic case history did the heavy lifting, seeming to provide motivation and context that abstract lectures often lack. This suggests broader applicability across engineering and science disciplines, especially in materials science, failure analysis, or systems engineering courses.

APPENDIX I. MINI CASE SUMMARIES

- Eroded Dam—Burrowing Animals (Week 2; Soil Classification). Students prioritized questions about seepage pathways and material heterogeneity; the instructor inserted a compact segment on grain size distribution and index limits to interpret observed piping. Teams then categorized soils and hypothesized failure progression. In the comparison section, soil classification was introduced via lecture/demonstrations and a worked example, without live case inquiry.
- Beach House Cracking—Dewatering (Week 3; Site Investigation). Student questions focused on drawdown history and foundation type; just-in-time content covered hydrostatics, subsurface profiling, and basics of planning a site investigation. Students proposed a minimal investigation program and sanity-checked expected movements. The comparison section delivered the same concepts via lecture plus homework.
- Leaning Tower of Pisa—Consolidation/Bearing Capacity (later weeks). Students connected long-term settlement to consolidation mechanics and later revisited the case for bearing capacity, seeing how a single complex failure scaffolds multiple core topics. The comparison section covered these as separated lecture units.

APPENDIX II. CLASS SEQUENCING

Class Segment	Time Allotted	
	50 min class	75 min class
1 Case framing	5 min	7 min
2 Student questions & ranking	3-5 min	10-15 min
3 Targeted concept exposition (interwoven with Q&A)	12–15 min	20-25 min
4 Guided solutioning/calculation	18–20 min	25-27 min
5 Professional/ethical reflection	3–5 min	5-7 min
6 Wrap/exit check	2–3 min	3-5 min

APPENDIX III. LEARNING PERCEPTION SURVEY QUESTIONS

Affective learning scale items

- I enjoyed this class.

- The instructor was very effective at teaching the material.
- I found this class thought provoking.
- I found this class very engaging.
- In this class I took an active part in the learning process.

Cognitive learning scale items

- I feel like I learned a great deal from this class.
- The instruction in this class helped me in learning the course concepts.
- I think I will retain most of the content I learned in this class.
- I could apply the concepts I learned in this course to understand real world situations.

DATA AVAILABILITY STATEMENT

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request. Specifically, the models and the code used to analyze data are available. Some or all data, models, or code generated or used during the study are proprietary or confidential in nature and may only be provided with restrictions. Specifically, student data is protected by confidentiality agreement.

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NOTATION LIST

The following symbols are used in this paper:

e = Void ratio of soil;

G_s = Specific Gravity of Solids;

H = Thickness of the soil layer;

S = Degree of saturation;

w = Water content;

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TABLES

Table 1. Forensic case studies and abstract concepts

Case#	Murder mysteries	Abstract concepts
1	The case of the collapsed boiler house	Phase relation
2	The case of the eroded dam - How burrowing animals cause dam failures	Soil classification
3	A beach house cracking in Corpus Christi due to dewatering	Site Investigation
4	Collapse of tunnel construction in Taiwan caused by seepage flow	Darcy's law
5	Why do dogs dig shallow pits?	Stresses in soil
6	Can we build an underwater sand castle?	Pore water pressure
7	Uprooting of a swimming pool in Florida	Compaction of soil
8	Closing agricultural wells in a runway in India	Consolidation
9	Flood levee construction in the state of Washington	Settlement
10	What does a bag of chips have to do with the leaning tower of Pisa?	Shear strength in soils
11	Constructing an airport on water - how to build an artificial island	Seepage failure
12	Shoal creek landslide in Austin	Shear tests
13	The walking dam in Pennsylvania	Foundation design
14	Inverting the Golden Gate bridge to build a 15th century Chapel	
15	Bearing capacity failure of leaning tower of Pisa	

Table 2. Examples of questions posed by the students to solve the murder mystery of the boiler house, corresponding answers, and student ranking for each question.

#	Questions posed by the students	Answer	# upvotes (out of 58)
1	<i>What kind of soil material was the boiler room built on?</i>	Clayey soil	33
2	<i>What is the type of foundation?</i>	A raft foundation resting on clayey soil	30
3	<i>Was the boiler load larger than the safe load? (students applying structural engineering knowledge of load-bearing)</i>	No, the foundation was over-designed and can safely sustain the load	23
4	<i>Were there any adverse weather conditions?</i>	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	<i>Where is the water table?</i>	the water table is 2 m below the foundation, and the soil voids (pore space) are saturated with water	11
6	<i>Did the heat from the boiler cause shrinkage in the soil? *</i>	Yes! Mystery solved!	10
7	<i>Was the subgrade properly compacted?</i>	Clayey soil cannot be compacted easily and does not respond to mechanical compaction.	4
8	<i>Has the clay been treated before with lime?</i>	No	4
9	<i>How thick was the foundation?</i>	The answer was unknown to the author and discussed live during class	3
10	<i>Could water leak into the soil from the boiler?</i>	No, the boiler did not leak until the failure	2

Note: Question marked with a * denotes the solution to the mystery

Table 3. Percentage distribution of student characteristics for the two sections at the beginning of semester.

Characteristic	Murder Mystery <i>n</i> =45	Comparison <i>n</i> =48
Year in college		
3 rd or less	68.89	62.50
4 th or more	31.11	37.50
Gender		
Male	51.11	62.50
Female	46.67	35.42
Non-binary	2.22	2.08
Race		
White	66.67	64.58
Black or African American	2.22	6.25
Asian or Asian American	31.11	25.00
American Indian or Alaska Native	0.00	4.17
Ethnicity: Hispanic, Latinx, and/or Chicax		
Yes	33.33	33.33
No	66.67	66.67
First generation status		
Yes	33.33	18.75
No	66.67	81.25
Level of mother's education		
Associate degree or less	42.22	31.25
Bachelor's degree or more	57.78	68.75

Table 4. Summary of mixed design ANOVA results

Variable	Partial SS	<i>df</i>	MS	F-statistic	p-value
Confidence					
section	0.56	1	0.56	1.26	0.27
time	2.13	1	2.13	6.57	0.01
section x time	1.42	1	1.42	4.40	0.04
error	20.07	62	0.32		
Interest					
section	0.51	1	0.51	0.81	0.37
time	0.16	1	0.16	0.54	0.46
section x time	1.78	1	1.78	5.86	0.02
error	18.79	62	0.30		
Perceived Course Difficulty					
section	2.61	1	2.61	4.86	0.03
time	8.26	1	8.26	26.53	0.00
section x time	2.06	1	2.06	6.63	0.01
error	18.68	60	0.31		

FIGURE CAPTION LIST

Fig. 1. The mystery of the collapsed boiler house showing the reason for failure. The students are only shown the illustration of the boiler house above the floor level (reproduced after Bolton (2013)).

Fig. 2. Change in confidence from the beginning to the end of the semester for the two sections.

Fig. 3. Change in interest from the beginning to the end of the semester for the two sections.

Fig. 4. Change in perceived course difficulty from the beginning to the end of the semester for the two sections.

Fig. 5. Self-perceived learning at the end of the semester.

Fig. 6. ‘Before vs. after’ comparison of the lesson structure in Murder Mystery section.