Implementing and Assessing a Game-Based Module in Geotechnical Engineering Education

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ABSTRACT

The GeoExplorer project is an ongoing effort aimed at addressing educational gaps related to field testing and practical experience in geotechnical engineering education. A computer game-based module was developed to supplement traditional lecture techniques and take advantage of technology familiar to today's students. To date, three different versions of the GeoExplorer module have been implemented at four different higher education institutions in the United States to 480 students in total. The final module consisted of a lecture to teach Cone Penetration Testing (CPT) procedures and analysis using traditional methods and demonstration photos and videos as well as a virtual internship experience where context of the virtual field testing environment is provided through a mock internship with a fictitious company. In between implementations, instructor feedback and student surveys were used to iterate over the module and different existing curriculum to work towards our vision of a mixed reality game, one that blends existing curriculum activities with virtual ones. In this paper, we describe our initial impressions of the results of these implementations and reflect on differences in student learning gains on different campuses. The resulting insights shed light on the constraints, difficulties, and

opportunities for game-based learning in geotechnical engineering education, particularly as it relates to building a module that is equally effective in fostering student learning in a variety of different classrooms.

INTRODUCTION

Game-based learning is continuing to find its way in education. The ability of games to engage and situate students in realistic scenarios (Gee 2003), including situations that are difficult to experience in reality, is a major reason for this continued expansion. Another is the ability to unobtrusively collect behavioral data (El-Nasr et al. 2013) and that, in fact, playing the game can be seen as a form of assessment (Shaffer and Gee 2012). When players play well, and the game's challenges are aligned with the learning objectives (Boyle et al. 2015), then we can translate their performance as evidence for understanding the learning material. Finally, though more evidence is warranted, there is an increasing number of studies that prove the potential of games for education (Bodnar et al. 2016). This conclusion also applies to engineering education specifically, where there is a general trend that both student learning and attitudes are improved by game-based activities, but also where there is a need for more evidence obtained through systematic, validated approaches (Bodnar et al. 2016).

In the past decade, gaming has gained widespread attention as a powerful educational tool (Harteveld 2011). Among other benefits, games provide immediate formative and summative feedback (Gresalfi and Barnes 2015) in a virtual space that creates authentic context (Gee 2003, Squire 2011), can serve as a tool for "capturing and maintaining" learning motivation (Orvis et al. 2008, Papastergiou 2009, Wiggins 2016, Yang 2012), and can position users as experts, giving them the ability to enact practices that they typically do not have access to in the real world. In their report, the Federation of American Scientists (2006) concluded that games may be especially effective in developing such higher-order skills as decision-making because "in games, players are making decisions continually, in contrast to low levels of decision-making in traditional learning" (p. 43).

As for game-based learning in engineering education specifically, a recent engineering education literature review found 191 papers published since 2000 where an educational game was used for an undergraduate engineering course (Bodnar et al. 2016). Of these, only 62 papers report on the learning outcomes, suggesting a dearth in empirical evidence about game-based learning environments; however, the analysis indicates that 87% of these papers report positive, 13% neutral, and 0% negative student learning outcomes. The authors therefore conclude that there "is a general trend that both student learning and attitudes are improved by game-based activities." In another review on games in engineering education (Deshpande and Huang 2011), the authors conclude that "adaptation of simulation games for engineering education remains a challenge" (pp. 399-400) and "is gradual and still not widespread" (p. 408). Therefore, while there are positive experiences, there continue to be reasons why game-based learning is still not widely in use.

Unfortunately, developing games is extremely time consuming and expensive, with development times of a professional game production ranging from one to multiple years and costs going from $100K up to multiple millions, excluding overhead (Academic Consortium on Impact Games 2012). Second, there is an incredible lack of dissemination of the games that have been developed. In a state-of-the-art review on games in engineering education, Deshpande and Huang (2011) conclude that "Adaptation of simulation games for engineering education remains

a challenge" (pp. 399-400) and "is gradual and still not widespread" (p. 408). Combining this with the relatively short product life cycle of games – because student expectations will increase based on the fast-changing game industry and because teachers lose interest in repeating the same module after some time – results in a pressing need to consider the adaptation of existing games for education and to develop a sustainable methodology for how to accomplish this successfully.

In this project, we focused on iterating the design of an existing game and disseminating it to four different institutions: two private research universities, a private liberal arts college, and a large public university. We redesigned this existing game, originally called CPT-Operator and developed for professional development on how to conduct a Cone Penetration Test (CPT), into a game-based module called *GeoExplorer* and refined this module over four years of implementations in existing geotechnical engineering courses. Based on the evidence of the success of blended learning environments (Orvis et al. 2008), we conjectured that integrating games with existing classroom activities would make them more effective. Such a "mixed reality" game, a game that combines and integrates virtual experiences with real environments, would make the experience more authentic, engaging, and – most importantly – would help with learning the other material offered in the classroom and facilitate learning the material provided through the virtual environment. Therefore, we aimed to both re-use and adapt an existing game as well as explore how to blend this with existing classroom activities. The *GeoExplorer* gaming environment also has the potential to provide instructors with a means of assessing student learning gains in engineering judgement through analysis of embedded game-play analytics. This kind of assessment allows for more comprehensive scoring of student competencies, alleviates test-related anxiety, and affords flow states in learning.

In this paper, we describe our initial impressions of our development process based on conversations with instructors, direct observations from implementations, and preliminary analyses of surveys and game data. We describe our educational context, the original CPT-Operator, and our initial aims. Following this, we describe the three different versions of *GeoExplorer* and the preliminary reactions from pre/post-surveys and game data obtained from implementations of the final version. We conclude the paper with the constraints, difficulties, and opportunities for game-based learning for engineering education.

GEOEXPLORER DEVELOPMENT GOALS

Geotechnical engineering practice depends on proper use and interpretation of field and laboratory testing of soil. Unlike other branches of engineering where practitioners have greater control over the materials they use, geotechnical engineering depends heavily on field exploration and experience. Geotechnical engineering education has been mainly focused on a limited number of small sample laboratory experiments because it is geographically and cost prohibitive to conduct actual field tests with students. There is also a current prevalent lack of an affordable and reliable way to educate and train students. We aimed to address this educational gap in geotechnical engineering education through the development and implementation of *GeoExplorer*. For developing this game-based module, we kept the following three goals in mind: re-using an existing game, anticipating dissemination, and mixing virtual with real activities.

Goal 1 – Re-Use of an Existing Game: We were aware of the difficulties for developing educational games. We identified a suitable existing game called *CPT-Operator*, developed by

Deltares, an independent applied research institute in The Netherlands focused on the fields of water, subsurface exploration, and infrastructure. Deltares partnered with the research team for this project and shared the *CPT-Operator* code. In this game, players have to perform several Cone Penetration Test (CPT) scenarios under varying circumstances. CPT is a valuable soil investigation field test for geotechnical engineers, which provides detailed information on the subsurface soil profile and the corresponding material properties. In this game, the goal for every exercise is to conduct a successful CPT. To accomplish this, players take control of a CPT truck, a truck specifically designed for conducting CPT tests. They drive this truck (with the least amount of damage) to a CPT location and then decide on the necessary preparations to conduct the CPT, which includes putting on work clothes, predigging the CPT location, choosing the cone, and leveling the truck. Once these preparations are done, players have to verify the calibration values and once these are OK, they can start the actual CPT. At this point in the game, players have to closely monitor the results displayed on a computer in the truck to make the decision of when to stop the CPT. After players decide to stop the CPT, the exercise ends, and players receive a score and feedback on their driving, preparations, and the actual CPT.

Goal 2 – Anticipate Dissemination: We were also aware of the challenge of dissemination and chose from the onset to implement the game at four targeted institutions. Our aim here was to ensure that we would get a variety of different perspectives on the game and could account for that in its development. Otherwise we would run the risk that the game would be tailored to work in one classroom and this would clearly limit the future likelihood of adaptation from other geotechnical instructors. Additionally, as Mayo (2009) suggested, we will have to implement game-based learning in our own educational initiatives to learn if games can help for science and engineering education. By implementing at various institutes with different instructors and student populations, we would learn more about the use of games for engineering education.

Goal 3 – Mix Virtual and Real Activities: We aimed to develop a mixed reality game, a game that would combine and integrate virtual and real activities. In our context the "real" activities consist of the traditional classroom activities (e.g., lectures, laboratory experiments, the use of websites); the "virtual" activities are those that occur in the virtual environment, such as conducting a CPT. We conjectured that such an approach would be more effective. We were inspired by the award-winning game *SharkWorld*, a singleplayer game where players take up the role of a project manager that has to build a shark aquarium in Shanghai (Yang 2012). While playing *SharkWorld*, players receive emails and text messages from game characters, which blurs the line between game and reality.

Similarly to this game, for *GeoExplorer* we anticipated making use of the mobile phone and conjectured that this would be a key device to connect all learning activities. In fact, Schwabe and Göth (2005) argued that "Mobile Technology enables immersion into a mixed reality environment and more motivating learning experience…mixed reality environments are much more apt to augment learning than purely physical or purely digital environments" (p. 214). Therefore, for *GeoExplorer* we were not just making a game as one thinks of in the traditional sense. We were making a game that is integrated with traditional classroom activities, hence why we refer to it as a "game-based module." Additionally, we were contemplating how we could harness the potential of mobile technology to increase its overall impact.

ITERATIVE DEVELOPMENT OF GEOEXPLORER

In this section, we describe in detail the three versions that have been developed: *CPT-Operator 2.*0, *GeoExplorer 1.0*, and *GeoExplorer 2.0*. We also provide the high-level insights from their implementation.

CPT-Operator 2.0: First, we decided to make minimal adjustments to the original *CPT-Operator* and focused on how this game is received in US classrooms. For this version, which we refer to as *CPT-Operator 2.0*, we removed all unnecessary elements, adjusted the language, better aligned the scoring with the learning objectives, and included specific scenario values based on the learning objectives for each scenario (Fig. 1). This game-based module was conducted in one class period lasting approximately two hours. Prior to playing the game, a lecture was given to teach CPT procedures and analysis using traditional methods (PowerPoint and written notes) and demonstration photos and videos. The assignment was to complete two specific scenarios (shallow foundation at a farm and land reclamation) out of a total of four available in the game (pile foundation in an industrial area and a levee). This game-based module was only implemented in junior-level soil mechanics courses at two private research universities in 2015 and 2016.

Figure 1. Screenshot of *CPT-Operator 2.0*, including the CPT truck and the Dutch landscape. At this point in the game, the player still has to navigate to the exact CPT location as indicated in the map.

The students (n = 132) were generally very positive. Over 90% of students agreed or strongly agreed that the game is an effective way to put what they learned into practice and 81% agreed or strongly agreed that the game is fun (Bennett et al. 2017). One student commented later that the experience was useful for her internship during which she had to perform CPT. On a critical note, students stated that they felt the experience lacked challenge, specifically in analyzing the data they retrieved from the CPT. They also commented on the driving: that it was long and somewhat difficult.

GeoExplorer 1.0: For the next version, *GeoExplorer 1.0*, we decided to make significant changes. We created a new environment where all scenarios are integrated into a single landscape, giving the perception that this is an actual space where players have to perform their activities, and visually made it more representative of a landscape in the USA (i.e., *CPT-Operator* was set in a Dutch landscape). Another reason for this single landscape was that it could serve for other civil/geotechnical engineering activities, not just CPT. Our future vision is

that *GeoExplorer* could become a virtual playspace for all kinds of engineering activities. Others who want to use game-based learning can then re-use and adapt it.

We further redesigned the scenarios such that instructors could easily change the parameters of each exercise and are able to add new scenarios, all of which we conjectured would help future adoption. Unfortunately, this meant that many idiosyncratic, hardcoded elements of each scenario from the original *CPT-Operator* had to be removed (e.g., requesting the farmer to open the gate or bringing a permit to enter the industrial area), which playtesters found enjoyable and missing from this version. Information provision (e.g., GPS, goals, scores) happened through an in-game mobile phone interface (Fig. 2) with the idea that this could be displayed on an actual mobile phone in the future. After completing their CPT, players receive graphs and a spreadsheet with virtual data derived from real data but based on how they conducted their test. The scenario ends when they make a preliminary analysis, which includes submitting a new spreadsheet with their calculations and answering their boss with what soil type they observed at a particular depth below the ground surface.

Figure 2. Screenshot of *GeoExplorer 1.0*. The player is now inside the truck and prepares for the CPT. Notice the mobile phone in the bottom-right corner.

To integrate the various activities better, we included a light narrative where players started with a new company called Terra Inc. and have to report to their boss. At the start and end of the second scenario, this boss asks a number of questions to assess players' knowledge and confidence on conducting CPT.

This version was extensively tested throughout 2016, but only implemented at two institutions (n = 80) in Spring 2017 in a similar vein as with the *CPT-Operator 2.0*. In contrast to *CPT-Operator 2.0*, we did not receive critique regarding the lack of analytical challenges; however, it was noticeable that the process of submitting the analysis results (spreadsheets) was confusing. Students still commented on the difficulty with driving.

GeoExplorer 2.0: Prior to developing the third version, named *GeoExplorer 2.0*, we discussed what to prioritize with previous and future instructors. It became clear that, for just the topic of CPT, the preference was an implementation in a single class period and to have students play during class – either in a computer lab or by asking students to bring their laptops to class. From previous implementations it was evident that most students were able to play two scenarios within this time period. As we developed four scenarios and extensively tested each of them, we allowed students to choose what scenario they wanted to play, in any order. We also told them they were able to complete all scenarios after class.

The continued limitation to one class period meant that we had to postpone our original idea of using mobile phones as a means of interweaving all educational activities. This would work with multiple topics crossing multiple class periods, but for a single class period it would impose too much without a clear educational benefit. However, within the constraints given, we continued to think about how to make this more of a mixed reality game and we settled on using a website that would represent the fictitious company Terra Inc. and positioned all activities more clearly as part of one integrated module.

GeoExplorer 2.0 works as follows. Students are asked to apply for an internship at Terra Inc., a geotechnical engineering company that designs solutions for complex civil engineering projects that are ethical, environmentally friendly, and sustainable. They go to the company website, sign up for the internship, and then get access to a dashboard that shows what missions are available to complete. Unlike with the previous versions, each mission has a specific context and outcome. While the missions are the same as the four scenarios in the previous versions, this context should help provide more relevancy to why students are performing a CPT. Each mission also comes with an achievement/badge, which highlights the outcome of the mission (e.g., solar panels or wind turbines). Then, if students complete any two missions they get the "CPT Master" achievement; if they complete all four missions they get the "CPT Champion" achievement. We included this to encourage students to complete as many missions as possible.

Before students can choose their first mission they first have to attend a professional training session from a company consultant. This involves the traditional lecture. The instructor roleplays this part of the game-based module. After that, students choose a mission, and enter the "virtual environment" using their credentials from the Terra Inc. website. Once they completed a mission, they go back to the website and have to submit a report with their findings. While more arduous, the sequencing of retrieving and then analyzing data is more realistic and we conjectured it would give a stronger perception of blurring the line between game and reality.

This version was implemented at all four institutions in Fall 2017 and Spring 2018 (n = 265). Fortunately, it became clear that the addition of the website was not a problem at all. Students signed up a day in advance of the class period, and a similar schedule played out as with previous implementations. In addition, from the open responses, it became clear that students picked up on the idea of the internship, which seems to suggest that our reframing was successful. However, students continued to express their dissatisfaction with the driving, despite another significant effort to address this issue.

Preliminary Results from GeoExplorer 2.0. To assess the implementations with each version, we used pre/post-surveys and game data (i.e., what decisions players made while playing and how they performed). The following are very preliminary results from assessment data collected in the Fall 2017 and Spring 2018 implementations. These results are included only to give an indication of the potential impact of this classroom innovation; further analysis is necessary. As an example of data available for future analysis, students used the scale of "the lecture was much more effective than the virtual internship" to "the virtual internship was much more effective than the lecture" to answer questions such as "learn more about geotechnical engineering" and "learn about the site investigation methods that are relevant to geotechnical engineering."

Overall, for *GeoExplorer 2.0*, students indicated that they were satisfied with the experience (M = 3.1, SD = 0.62; scale 1 to 4) with 22% students being extremely satisfied and only 8% expressing dissatisfaction. Students found *GeoExplorer 2.0* to be effective in teaching the CPT content (M = 15.8, SD = 3.11; scale 4 to 20, α = .94); to help increase perception of

geotechnical engineering relevance (M = 22.4, SD = 4.46; scale 6 to 30, α = .96); and, for a significant group (36% scored 16 or higher), to increase interest in pursuing a career in geotechnical engineering (e.g., a graduate degree in geotechnical engineering, employment with a geotechnical engineering firm, etc.; M = 13.8, SD = 3.56; scale 4 to 20, α = .94). In addition, the game data illustrate interesting patterns in development of students' engineering judgment competency over time, which we aim to further explore. Finally, the students expressed that the website inclusion and narrative context of a virtual internship made the experience feel "more real": students' open-ended responses indicated their appreciation of gaining practical experience ("It gave me an experience on [sic] the field while in a classroom" and "the game shows what happens in real life") and the ability to analyze "real" data. Some called the experience "perfect just the way it is" and others wanted more of it: "Make there be more issues, more things we'd experience on [sic] the field."

CONCLUSION

In this paper, we describe an ongoing effort for developing and implementing game-based learning in geotechnical engineering education, specifically on the topic of Cone Penetration Testing (CPT). CPT is a valuable soil investigation field test for geotechnical engineers. We achieved our initial aims for this project, which were focused on addressing specific challenges and opportunities for educational games in general, and our approach to accomplish this was to: (1) re-use an existing game instead of building one from scratch; (2) anticipate dissemination from the onset to foster adaption instead of building a game custom-made for a specific context; and (3) mix virtual and real activities to better integrate games into the classroom and increase their overall impact.

The development process led to three different versions of the game, which were implemented at four different institutions with about 480 students in total. The first version was a modification of the original game; the second included an aesthetic overhaul but is more distinctly different for its inclusion of a data analysis phase; and the third version accomplished our idea of a mixed reality game by reframing the activity as an internship and adding a fictitious company website.

Reflecting on this work thus far, our lessons learned are:

1. Re-using an existing game is still a significant effort. It took more time to complete *GeoExplorer* but also the iterations were needed to fine-tune the game. Therefore, while re-using is a sustainable approach for game development, the time and effort should not be underestimated.
2. Integrating a game with existing activities needs to be done thoughtfully but can make for a significant change with relatively little effort. Our work shows that the sequence of activities may not always be logical, and that testing is needed to get it right.
3. Working with different institutions from the onset proved, in our case, to work well, as the game was implemented with limited difficulties and all institutions continue to be committed to use it. This suggests that our approach of co-designing the module curriculum and involving stakeholders from the onset proved to be successful.
4. Even after years of iteration, with students but also with professional help, it is still quite hard to achieve the level of refinement and quality of entertainment games, evidenced by the continued criticism on driving. This is not surprising considering the budgets available to produce entertainment games. Thus, it is important to set realistic expectations and/or accept

that certain aspects of a game might be a little frustrating. In our case, we continued to include the driving component as we deemed it to enhance the overall experience.

5. All versions were met with very positive student perceptions and assessment results. Therefore, the students welcome game-based learning in their education and our preliminary study results show evidence for the game's effectiveness. This finding is consistent with other efforts reported on the use of game-based learning in engineering education (Bodnar et al. 2016, Deshpande and Huang 2011), further strengthening the potential of games for engineering education.
6. Students take their learning seriously, something we observed elsewhere too (Harteveld et al. 2012). They demand to learn (more analysis, less driving) and be challenged.
7. A potentially more transformative outcome is that students not only indicated that they learned from it, but that playing the game increased their awareness of the relevance of geotechnical engineering and their interest to pursue a career in this field.

Our near future work involves performing a comprehensive analysis of all data (surveys, game data) to achieve more conclusive evidence on our implementations and the use of game-based learning of engineering education.

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