Classroom implementation of game-based module for geotechnical engineering education

Victoria Bennett, Rensselaer Polytechnic Institute

Professor Victoria Bennett is an Assistant Professor in the Civil and Environmental Engineering Department at Rensselaer Polytechnic Institute (RPI). She is interested in improving undergraduate engineering education through hands-on, experiential, and game-based learning.

Dr. Tarek Abdoun, Rensselaer Polytechnic Institute

Professor Dr. Tarek Abdoun is the Iovino Chair professor and associate dean of Research for the School of Engineering at Rensselaer Polytechnic Institute (RPI). He is the technical director of NSF Network for Earthquake Engineering Simulation (NEES) Facility at RPI.

Dr. Casper Harteveld, Northeastern University

Dr. Casper Harteveld is an Assistant Professor of Game Design at Northeastern University, has affiliated appointments in Computer Science, Electrical & Computer Engineering, Mechanical & Industrial Engineering, and with the School of Law, and works closely with faculty in Marine Science and Public Policy. His research focuses on using games to study and improve decision-making, and through these efforts both to advance our knowledge and to engage a broad cross-section of people globally about societal issues. He applies games especially in areas where it is challenging to study and educate in natural environments and collects detailed and expansive behavioral data in a controlled manner.

Working across disciplines, Dr. Harteveld has designed and evaluated games on flooding, urban heat islands, debris collection, and pro se litigants. He is a strong proponent of integrating research and education and a significant portion of his work is devoted to translating research outcomes to the classroom or informal settings, in order to make sure that the next generation is ready to deal with the societal challenges of the 21st Century.

Dr. Flora P McMartin, Broad-based Knowledge, LLC

Flora P. McMartin is the founder of Broad-based Knowledge, LLC (BbK), a consulting rm focused on the evaluation of the use and deployment of technology assisted teaching and learning. Throughout her career, she has served as an external evaluator for a number of NSF-funded projects associated with faculty development, community building, peer review of learning materials, and dissemination of educational innovation. She was PI for the project “Learning from the Best: How Award Winning Courseware has Impacted Engineering Education.” This research focuses on determining how high quality courseware is being disseminated and what impact it is having on the culture of engineering education as measured by changes in student learning, teaching practices, and the careers of the authors of these materials.

Dr. Usama El Shamy P.E., Southern Methodist University

Dr. Usama El Shamy is an associate professor in the Civil and Environmental Engineering Department at Southern Methodist University. He received his Ph.D. in Civil Engineering from Rensselaer Polytechnic Institute in 2004. He is the Principal Investigator and Project Director of the NSF funded TUES-Type 1 project: "A Multi-Institutional Classroom Learning Environment for Geotechnical Engineering Education.”
Classroom Implementation of Game-Based Module for Geotechnical Engineering Education

Abstract

This paper highlights an ongoing effort to address the educational gaps in geotechnical engineering education through the development and implementation of a transferable and scalable Mixed Reality and Mobile (MR&M) Educational Game, “GeoExplorer.” A game-based course module was implemented in existing geotechnical engineering courses at Rensselaer Polytechnic Institute (RPI). The newly developed game has the potential to transform the way geotechnical engineering is taught by addressing the current critical gap of lack of exposure to field testing and practical experience. Ultimately, the use of MR&M games should result in a better-trained and globally minded workforce. The game will be available for free for educators and its implementation does not require additional resources. The game-based module is flexible and variations of the game can be scaled with little difficulty, depending on the targeted audience.

The formative evaluation of the curriculum module was designed to ensure that the game addressed the module’s learning outcomes and included appropriate metrics for measuring student learning. To achieve these assessment goals, pre-game and post-game implementation surveys were conducted. The classroom implementation included a lecture to teach Cone Penetration Testing (CPT) procedures and analysis using traditional methods and demonstration photos and videos. Then students were asked to take the pre-game survey, which included technical questions designed to evaluate their learning. This was followed by introducing the CPT portion of the GeoExplorer game to the class. After completing the game assignment, the students completed the post-game survey, which included the same technical questions, as well as additional questions designed to assess game quality and students perception of its effectiveness. Findings from these surveys will be discussed herein. One noteworthy finding was that over 90% of students agreed or strongly agreed that the game is an effective way to implement class learning into practice.

Introduction

Educators are tasked with preparing undergraduate students to become professionals who are knowledgeable about and engaged in dealing with the challenges of today’s society, such as infrastructure resilience and sustainability. This requires students to acquire relevant practical experience, which cannot be achieved with current teaching techniques (Pellegrino & Hilton, 2012). Although students are taught risk and cost-benefit analyses, they do not experience how to deal with adverse events throughout their education. Recent weather extremes, e.g., Hurricanes Sandy and Katrina, have shown the consequences of the combination of a deteriorating infrastructure and a citizenry that is unprepared to deal with natural disasters of this scale. To overcome the societal challenge associated with the deteriorating infrastructure in the United States and worldwide, this lack of practical experience needs to be addressed and students should be provided with opportunities to engage in challenging, real-world problems.
In order to educate a professional workforce who is properly trained in STEM, able to identify warning signs of system failures, and capable of making the right decisions, undergraduate engineering students must be provided with certain skills while they acquire the relevant practical experience. ABET suggests that undergraduate engineering students should, “learn from failure,” “identify health, safety, and environmental issues, and deal with them responsibly,” and “use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems” (Feisel & Rosa, 2005, p. 127). These skills are considered sense-making capabilities. The concept of sense-making (or the process of decision-making) is about learning how to deal with new, rare, or complex phenomena and is of importance in responding to societal challenges such as adverse events (Weick & Sutcliffe, 2007).

Game-based learning has the transformative potential to address the lack of practical experience in geotechnical engineering, while also utilizing a technology that is familiar to today’s students. Games enable people to safely experience and learn about new, rare, or complex phenomena in an authentic virtual environment. Mayo (2007) stated that “While there will never be a silver bullet for science and engineering education, video games have the potential to be, perhaps, a bronze bullet. But only by using game-based learning in our own educational initiatives, assessing and improving along the way, will we know whether U.S. national competitiveness can be restored through something as fun and engaging as playing a game” (p. 35). This project investigates the transformative potential of gaming in undergraduate geotechnical engineering education, with the particular aim of achieving 21st Century engineering education.

Training geotechnical engineering professionals who are able to handle the real-world challenges and constraints of the 21st century starts with students who are properly trained in the assessment of subsurface soil conditions and the design of earth structures (i.e., levees, dams, tunnels, etc.). Geotechnical engineering practice depends on proper use of field and laboratory testing of undisturbed soil samples that in many cases are difficult to collect. Soils are inherently random media and the information on the material properties and in situ conditions will always be incomplete if based only on small sample lab testing. Unlike other branches of engineering where practitioners have greater control over the materials they use, geotechnical engineering depends heavily on field exploration and experience. Unfortunately, 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 for the students. Currently, there is a prevalent lack of an affordable and reliable way to educate and train students on the variety of field testing, system health assessment, and the process of sound engineering judgment (sense-making), which are all required in practice. This project aims to address the educational gaps in geotechnical engineering education through the development and implementation of a transferable and scalable Mixed Reality and Mobile (MR&M) Educational Game, “GeoExplorer,” that will be integrated with traditional geotechnical engineering education. This MR&M game builds on the positive experience gained from two existing educational games, Levee Patroller and CPT Operator, developed by Deltares, an independent applied research institute in The Netherlands.
Use of Educational Games to Create Advanced Learning Materials

Games and Learning to Solve Real World Problems

The potential of educational games for transforming education has been identified in the past decade (Aldrich, 2004, 2009; Egenfeldt-Nielsen, 2007; Gee, 2003; Shaffer, 2006; Squire, 2011). Based on results from previous implementation, games provide an ideal tool to enhance engineering education by fostering sense-making capabilities (based on virtual practical experience), which are essential for the 21st century engineer.

Decision-making can be seen in terms of the event, i.e., the choice between two or more alternatives, or in terms of the process that leads to the commitment to an action. The process of decision-making is sometimes referred to as sense-making (Klein et al., 2006). According to Weick (1995) sense-making is a comprehensive process of constructing meaning out of an experience, which involves a motivated effort of understanding connections among people, places, events and what happens when people are challenged, surprised, or confronted with the unfamiliar. In other circumstances people can rely on routines and their existing knowledge. The input and output of a sense-making process is knowledge (Dervin, 1998): people make use of their existing knowledge to make sense of phenomena and based on their experience they acquire new knowledge. To understand sense-making, it can be decomposed into five components: recognizing, reporting, diagnosing, assessing, and taking action (Hartevedt, 2012).

In a study of the expectations of engineering professionals for undergraduate engineering students, Cox et al. (2012) reported that engineering leaders are expected to make use of the data around them to make informed decisions. This general sentiment was applied specifically to geotechnical engineers by one of the field’s prominent leaders, Ralph Peck, through the Observational Method (Peck, 1969). The Observational Method is based on observing and assessing geosystem response during and post construction and to continuously modify the design and construction based on revised analysis guided by the observed system response (used in projects such as the Big-Dig project in Boston, MA). To date, this approach is considered one of the most important methods in the field of geotechnical engineering, but it has been difficult to demonstrate in the traditional classroom setting. It was not until entering the workforce that students begin to understand the true value of field experience (and are able to acquire sense-making skills). In addition to providing the critically needed field testing experience, games provide students with a virtual environment to observe and evaluate geosystem response under different loading conditions and implement proper corrective measures or design improvements. Teaching using gaming can therefore help address the current gaps in geotechnical engineering education. If engineers learn sense-making capabilities, they are much more likely to efficiently and successfully recognize, report, diagnose, assess, and take action against possible threats. They will have their (virtual) practical experiences to draw upon, so what they face in practice will not be completely new to them.

Implementing educational games encourages problem-based learning, experiential learning, and situated learning and fosters deep learning by providing immediate and constant feedback, personalizing learning, and challenging players (de Freitas & Maharg, 2011; Gee, 2003, 2007; Squire, 2011). Games are also unique in their capacity to engage learners (Garris et al., 2002). Players may voluntarily invest countless hours in a good game. Because players engage in authentic and compelling learning environments when they play games, they will
better understand the relevance of their discipline, the need to learn certain material, and will
better realize the magnitude of the stakes (Shaffer, 2006). The concept of sense-making is a
natural fit with games because in game environments players have to make decisions continually
and this requires them to make sense of what they encounter (Federation of American Scientists,
2006). Within games, players further learn from their failures. Experiencing the consequences,
even virtually, is often more compelling than just hearing about them (Schank, 1997).

Research that focuses on the use of games in primary and secondary education confirms
their promise (e.g., Barab et al., 2005; Clark et al., 2011; Ke & Grabowski, 2007; Klopfer et al.,
2009) and also specifically with MR&M types of games (Klopfer, 2008; Klopfer & Squire, 2008;
Montola et al., 2009). The little work in higher education does so too (for a review on games in
engineering education, see Deshpande & Huang, 2008). For example, Coller and Scott (2009)
applied game technology with success for transforming a mechanical engineering course on
numerical methods at the undergraduate level into a game-based project. They note that the game
lets “students think about and value the academic subject material the way a professional does”
(p. 911). In addition, Delft University of Technology has been involved, for over a decade, with
successful game-based implementations in engineering education (Meijer et al., 2012).

GeoExplorer Game Concept

Two games serve as the foundation to GeoExplorer – Levee Patroller and CPT Operator. Levee
Patroller is a single player game. Players enter a 3D environment and interact with it from a first-
person perspective (Fig. 1). The player moves freely around the environment to find all potential
levee failures and appropriately deal with them using the tools of the game (e.g., handbook, map,
etc.). Dealing with failures requires players to Recognize them, marking the area of the potential
failure location. Subsequently, players have to Report the location of the problem and the signals
that constitute the potential failures and their characteristics. Next the player must communicate
the findings to a field office and Assess the severity of the situation. Failures can change over
time so players need to return to the problem locations to determine if the failure potential
worsened. After Diagnosing the situation, which involves determining what mechanism is
causing the impending failure, players can Take Action and implement a stabilizing measure. If
they do not implement this in time or use the wrong technique, a catastrophic failure and
flooding results. At the end of an exercise players receive a score based on how they recognized,
reported, assessed, diagnosed, and took action against failures.

Figure 1. Screenshots from Levee Patroller game – imminent levee failure and flooding.
CPT-Operator takes players through the whole process of making a Cone Penetration Test (CPT), a valuable soil investigation field test for geotechnical engineers (Fig. 2). The CPT test provides detailed information on the subsoil profile and the corresponding material properties. This game consists of three phases that together represent the complete process of an actual cone penetration test (CPT): preparation, field site access, and test completion. Players receive a score based on their performance in every phase. Players receive input from the game on sense-making skills. For example, it is possible to infer if players were able to recognize the cues and take the right actions.

![Screenshots from CPT Operator game – driving to field investigation site and player view from inside CPT truck.](image)

In the final version, the mobile platform of GeoExplorer will connect and store all module activities. Other than being a mnemonic device to students, it will be used to receive and provide input of activities. For example, after retrieving the lab test results, players will be asked to insert the measured data into their mobile device. This information, on its turn, can be used in any of the virtual environments or will be used in player interactions with their mobile device. Likewise, data from the virtual field test (CPT) will be communicated to the mobile and can be used to plan the physical lab tests, as to what tests need to be done and why. Game characters, such as local officials or representatives from the US government or the US Army Corps of Engineers, will contact players by means of text messages, e-mails, and pre-recorded phone calls. Pre-recorded phone calls will also be converted to e-mails, which are sent to the players in case they may have not completely understood the voice message. The use of text messages, e-mails, and pre-recorded phone calls gives players the feeling they are engaged with an actual project and not in a game. This has been proven through the award-winning game SharkWorld, a singleplayer game where players take up the role of a project manager (Harteveld et al., 2012). Special attention will be paid to ensure that the developed game is flexible and modular enough to be implemented in other school settings and is able to include additional topics and instructional material. The mobile platform will be cross-platform (i.e., both iOS and Android). Many game development tools, such as Unity, allow for easy cross-platform development. As not every student may have access to a smartphone or tablet, the game will be playable on just a laptop or desktop computer. As long as students have access to the Internet, they can play.

The goal of the complete GeoExplorer game is to design and assess a flood-protection levee at a certain flood-prone site. This is designed step-by-step (see Table 1), first by investigating the soil (Course Topic 1), then by exploring the subsurface (Course Topic 2), until
the inspection of seepage and slope stability (Course Topics 9 and 10). Throughout these steps, players gather the necessary information to design and assess this flood-protection levee. In the initial implementations of the GeoExplorer game, two-three week course modules that augment a few topics in a typical undergraduate geotechnical engineering course will be utilized. Course modules can be easily scaled and adapted in courses, which makes them more attractive to fellow faculty at other schools for adaptation in their respective courses. The planned target, which will be stated in the beginning of the semester, is to design and assess a flood-protection levee at a specific site. Starting from site investigation and identification of basic soil properties at the site, students will learn the lab experiments needed to complete the site investigation process. Students will then apply what they learn in the subsequent subjects to the soil profile at the site and the proposed levee as shown in Table 1. Such integration of the subjects to a real-life design problem will strengthen student understanding of the link between engineering theories, the lab experiments and the gaming environment. The course module is split over two project assignments. The first assignment utilizes CPT field testing capabilities of GeoExplorer, which is simple enough for a good introduction of the gaming environment to the students. The second assignment will utilize levee design and assessment capabilities, in which students will design a levee and examine its performance under several flooding and storm scenarios. While each assignment will be given over two weeks, throughout the semester the students will be engaged with issues related to the design of a levee system, as shown in Table 1. The gaming environment will emphasize field testing, sense-making and virtual practical experience as students play the different sessions of the game. Sense-making situations can be introduced as simply as guessing soil properties (e.g., unit weight, specific gravity, shear strength parameters, etc.) to the more difficult cases of predicting worst case loading scenarios of a levee for slope stability and seepage analyses.

The envisioned integration of the game module aims at providing the following learning outcomes:

• evaluate geotechnical systems using current principles of geotechnical and foundation engineering by experiencing (virtually) the actual response;
• select the proper set of experiments from the large number of lab tests in the course for the design and construction of the system (a levee in this case);
• develop virtual field test experience and integrate the results with lab testing results;
• develop sense-making as they define soil properties and make recommendations regarding design and construction;
• adapt and adjust experiments and design methodology due to virtual failure and re-engineering effective solutions; and
• become a motivated self-learner with desire for more in-depth learning through research, which will lead to pursuit of graduate studies or a career in research and development.
### Table 1. Course topics and associated activities

<table>
<thead>
<tr>
<th>Course Syllabus Topic</th>
<th>Activity Description</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Geological Characteristics of Soils</td>
<td>Visualization of soil layering at the site and identification of their rock formation</td>
<td>Actual lab testing*</td>
</tr>
<tr>
<td>2. Subsurface Field Exploration</td>
<td>1) Determination of number and depth of borings and selection of proper drilling equipment</td>
<td>Virtual game</td>
</tr>
<tr>
<td></td>
<td>2) Perform a field site investigation with CPT field testing</td>
<td></td>
</tr>
<tr>
<td>3. Physical Soil Properties</td>
<td>1) Conduct small sample laboratory testing (grain size distribution, direct shear test, etc.)</td>
<td>Actual lab testing*</td>
</tr>
<tr>
<td></td>
<td>2) Mark each soil layer and enter its physical properties along with corresponding classification</td>
<td></td>
</tr>
<tr>
<td>4. Shear Strength of Soils</td>
<td>1) Lab determination of shear strength parameters</td>
<td>Actual lab testing*</td>
</tr>
<tr>
<td></td>
<td>2) Interpret CPT data and compare to lab results</td>
<td></td>
</tr>
<tr>
<td>5. Permeability of Soils</td>
<td>1) Conduct lab coefficient of permeability test</td>
<td>Actual lab testing*</td>
</tr>
<tr>
<td></td>
<td>2) Conduct field permeability test</td>
<td></td>
</tr>
<tr>
<td>6. In situ Stresses and Distribution in Soil</td>
<td>Interactive determination of in situ stresses due to proposed levee (embankment) loading</td>
<td>Numerical analysis</td>
</tr>
<tr>
<td>7. Soil Settlement</td>
<td>1) Conduct lab consolidation test</td>
<td>Actual lab testing*</td>
</tr>
<tr>
<td></td>
<td>2) Prediction of settlement profile under the proposed embankment</td>
<td></td>
</tr>
<tr>
<td>8. Seepage in Soils</td>
<td>Check for subsurface piping as well as internal erosion</td>
<td>Actual lab testing*</td>
</tr>
<tr>
<td>9. Slope Stability</td>
<td>Check the stability of proposed levee slopes considering several flooding scenarios</td>
<td>Virtual game</td>
</tr>
<tr>
<td>10. Health Assessment and Long-Term Maintenance</td>
<td>1) Conduct field inspection under harsh loading conditions</td>
<td>Virtual game</td>
</tr>
<tr>
<td></td>
<td>2) Implement emergency retrofit and stabilization systems</td>
<td>Virtual game</td>
</tr>
<tr>
<td></td>
<td>3) Observe and assess the levee under several loading conditions</td>
<td>Virtual game</td>
</tr>
</tbody>
</table>

Data generated during actual lab testing will be used as input to gaming environment

Implementation in Existing Geotechnical Engineering Curriculum

The initial implementation of the GeoExplorer game was conducted in an undergraduate soil mechanics course, ‘Experimental Soil Mechanics.’ This elective course is the second in a sequence of soil mechanics courses (follows Introduction to Geotechnical Engineering) and is typically taken by civil engineering juniors and seniors. The first classroom implementation of GeoExplorer included a lecture to teach Cone Penetration Testing (CPT) procedures and analysis using traditional methods (PowerPoint and written notes) and demonstration photos and videos. Based on the preference of the instructor, lecture notes are not posted online or otherwise made available to students outside of classroom. Following the lecture, students were asked to take a pre-game survey, which included technical questions designed to evaluate their learning. This was followed by introducing the CPT portion of the GeoExplorer game to the class. The student assignment was to complete two missions out of a total of four missions (shallow foundation at a farm, land reclamation, pile foundation in an industrial area, existing levee) available in the game. After completing the game assignment, the students completed the post-game survey, which included the same technical questions, as well as additional questions designed to assess game quality and students perception of its effectiveness.

Twenty-three student survey responses indicated that they felt positive about the game and thought it added to their learning. Over 80% of the students reported that they had not played games in courses before and, somewhat surprisingly, the majority of students (72.7%) reported that they rarely or only sometimes played computer games (question included description of
games as those on tablets, smart phones and so forth for enjoyment). These results suggest that students are less familiar with gaming than perhaps assumed and even less familiar with serious games. Future design efforts with GeoExplorer, both associated with the game and the curriculum, will need to take into account potential training needs and a simplified user interface.

The pre / post survey included questions associated with learning specific concepts associated with site investigation and use of CPT. The results showed 20% improvement in understanding after using the CPT game. Students also reported 30% increased confidence in knowing about CPT procedures after using the game. Over 90% of students agreed or strongly agreed that game is an effective way to: 1) Implement class learning into practice (91%); 2) Conduct geotechnical site investigation (100%); and 3) Learn CPT testing procedure (95%). As implemented at this stage, the strength of the game is an increase in procedural confidence. The lecture is effective at communicating basic concepts of the CPT but potential improvements in procedural knowledge and subject engagement achieved by the mixed reality module will continue to be explored. Written student feedback also clearly indicated the need to include more soil classification and design analysis in the game.

Conclusions

The use of an educational game-based module to support undergraduate geotechnical engineering education has been implemented at two institutions and shows promise for the integration of several more universities in the future. The virtual testing environment facilitated an increase in confidence related to field testing, an experience typically cost prohibitive due to geographic and equipment constraints. The developed and pilot-tested education module has been verified by the student participants. It enhances the undergraduate classroom curriculum by tying in virtual experiences and actively verifying core concepts that have previously been presented in a traditional and passive manner. The complete game has the potential to improve students’ sense-making skills and transform the way geotechnical engineering is taught. Ultimately, the use of MR&M games, such as GeoExplorer, should result in a better-trained and globally minded workforce. Upon completion of this project, the game will be available for free for educators and its implementation does not require additional resources. The proposed game-based module is flexible and variations of the game can be scaled with little difficulty.

References


