Developing Mixed Reality Game for Enhanced Learning of Geotechnical Experiments and Geotechnical Design

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ABSTRACT

A fully-integrated mixed reality game system called multiphysics enriched mixed reality for integrated geotechnical education (MERGE) is developed to improve student education in the context of geotechnical engineering. Several minigames are designed for students to enhance their geotechnical knowledge. Players can earn points and update their appearance by playing these minigames, which stimulates their interests in geotechnical engineering. By providing students with visualization, collaboration, and simulation tools, we hope to promote the understanding of geotechnical experiments. Based on the laboratory results, numerical experiments are conducted to help students understand the geotechnical application. The leveraging mixed reality technology offers an opportunity for students to access advanced equipment in geotechnical experiments. The main contribution of this work is a discussion of the educational technology and processes behind implementing a mixed reality educational game. We provide developmental insights and educational background to inform researchers who seek to develop similar games.

INTRODUCTION

Geotechnical engineering is critical in addressing today's global issues like energy demand, environmental protection, infrastructure sustainability, and hazard mitigation. Recent challenges (e.g., climate change (Basu and Lee 2022; Petukhova et al. 2022), population increase (Souza and Savoikar 2022), and urbanization (Olga et al. 2020)) require future geotechnical engineers have greater education and outreach, which means recent students need more knowledge besides standard geotechnical engineering courses to handle these growing issues. For example, soil mechanics is a core course in geotechnical engineering. However, students have few opportunities to apply their knowledge into applications by experimental or laboratory work (Ferentinou and Simpson 2019; Shidlovskaya and Briaud 2016; Welker 2012). As a result, not only is education inadequate, but students would be bored or difficult with the courses, which jeopardizes efforts to recruit new students and workers in geotechnical fields (Agrawal and Dill 2008). Recent radical and transformative technological revolutions in cyberinfrastructure have resulted in fundamentally new approaches to engineering education.

Inspired by the mixed reality game, “Pokémon GO”, the multiphysics enriched mixed reality for integrated geotechnical education (MERGE) platform is developed in this study. The MERGE platform enables students to see computer-generated models overlaid in the actual environment using the camera on their mobile smartphones. Using current advances in cyberinfrastructure, MERGE aims to create an appealing and inspiring environment to boost students' geotechnical engineering abilities. Throughout gaming, students' strategic thinking will be assessed by means of geotechnical-related games that have been meticulously constructed. In addition, the game utilizes the player's GPS to construct a map of the actual world around them, allowing them to explore their immediate surroundings in order to advance the game. At the beginning of the game, players are tasked with a laboratory exercise involving the construction and study of geothermal piles which are special foundations that heat or cool the building using the earth’s temperature.

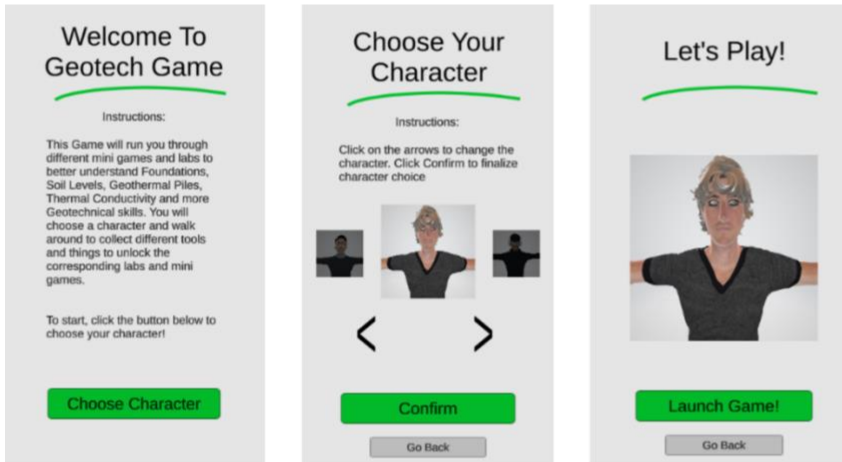
The mission of the MERGE platform is to strengthen and advance the education of students who are majoring in geotechnical engineering, particularly in the field of soil mechanics and other fundamental concepts. Our mission is to provide the students with an enriching educational experience while also maintaining their interest in a fun game. Students are able to participate in a continuous learning experience outside of the classroom when they are given the opportunity to interact with mixed reality representations of lab and field activities. This eliminates the requirement for students to have access to a lab or purchase pricey equipment. The game may boost students' incentives to study outside of the gaming environment by using technology known as mixed reality (Ebner and Holzinger 2007). In addition, the game gives new insights into geotechnical concepts via the use of intuitive simulations and models (Deshpande and Huang 2011). Students have unparalleled access to the availability of learning materials thanks to the comprehensive gaming system, which further stimulates students' learning and helps them learn more. We hope that by delivering educational content through this paradigm of virtual games, not only will we be able to engage students in the learning process, but we will also be able to encourage them to complete highly educational and enjoyable project work.

GAME OVERVIEWS AND DESIGN

Our mobile game has a main storyline along with minigames; both of them will have educational twists. These will expose students to a circumstance that an engineer would take to address difficulties in the real world. Two main game experiments, the thermal conductivity test and direct shear test, are designed with multiple unlocked minigames that teach students various abilities and concepts (e.g., soil levels, thermal conductivity, and tools available)of geotechnical engineering. Two minigames are initially available for the player on the map. The game then brings the player to the first experiment, the thermal conductivity test after the player has gained enough knowledge and gathered the relevant materials and tools. The technique is repeated for the direct shear test and accompanying minigames, enabling the player to progress at their own pace through the material. Following these two tests, a finite element method (FEM) simulation of thermal piles is created so that players may investigate the mechanism of thermal piles. In this simulation, players may utilize the thermal conductivity coefficient recorded in the thermal conductivity test as an input parameter to construct a numerical model of thermal piles. By altering the length of piles, the form of the pipes, and the temperature of the ground, etc., various numerical results will be shown to players, which teaches students how these factors affect the heat extraction effectiveness of thermal piles.

Avatar Choosing and Map

The first step for players is to choose their own avatar, which will represent their location in the virtual game world. There is a simple introduction about this game for players on the opening page when this application is first installed as shown in **Figure 1(a)**. The player can choose a favorite character as shown in **Figure 1(b)**. After that, the players can click "Launch Game" to enter the game, and then they will see their characters on the map.



(a) (b) (c)

Figure 1. Directions Opening Page: (a) game introduction; (b) confirm avatar; (c) launch game.

With the help of mapbox API, the phone's GPS location is used to give users the experience of viewing their local area. **Figure 2** shows an example map around Rowan University, and the players can rotate and zoom in and out around the map to access all the lab activities, minigames and collect items they need for other objectives.

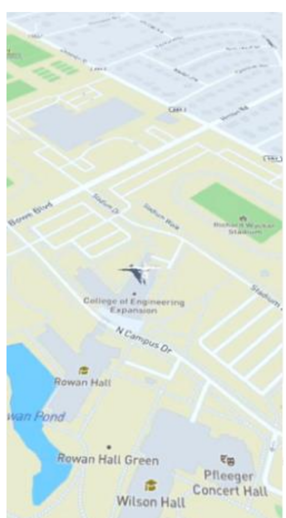


Figure 2. Example map around Rowan University.

Minigames

Several minigames (e.g., word searches, dig dug, spot difference, connect dots, and snake game) were designed in MERGE to encourage students to play this game and explore more in the virtual world. In the first game, word searches, the players would learn some geotechnical background and vocab they might use in the following game. During the dig dug game, the players need to gather different soil samples below the surface to fill their meter, and avoid obstacles at the same time. The spot difference requires players to spot some key components missing from the physical lab equipment in each photo, which helps players be familiar with some geotechnical lab equipment. The players can earn reward points through these minigames. They can use these points as a form of in-game currency, and change their clothes or redeem some tools with these reward points. Such minigames would rise the enthusiasm of students for this game, and help them learn some necessary geotechnical knowledge.

Experiments

Two geotechnical experiments, thermal conductivity test and direct shear test, were designed for students in this mobile game. The players need to look for different kinds of experimental tools used for these two experiments, such as hand rake, mold, and wash bottle as shown in **Figure 3**.

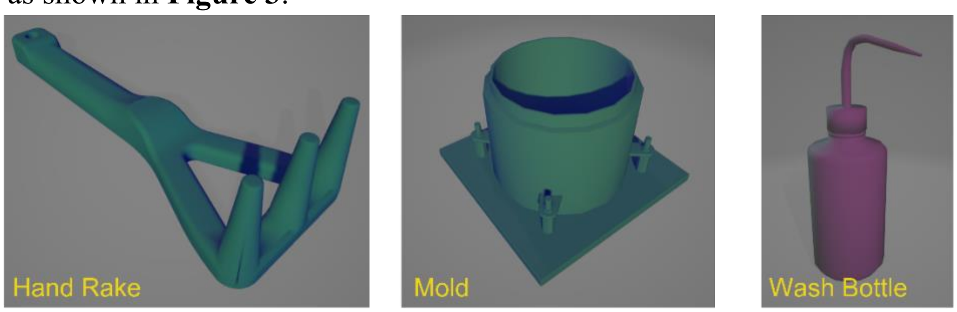


Figure 3. Virtual experimental tools in the mobile game.

The thermal conductivity test was used to determine the thermal conductivity coefficient of different soils under steady-state conditions, which is important for the design of underground power transmission systems. The virtual laboratory was built as shown in **Figure 4(a)**, which allows students to take the tests under different temperatures. The thermal conductivity meter as shown in **Figure 4(b)** was used to test the thermal conductivity coefficient of soils in the test.

(a) **(b)**

Figure 4. Equipment for the thermal conductivity test: (a) laboratory; (b) thermal conductivity meter.

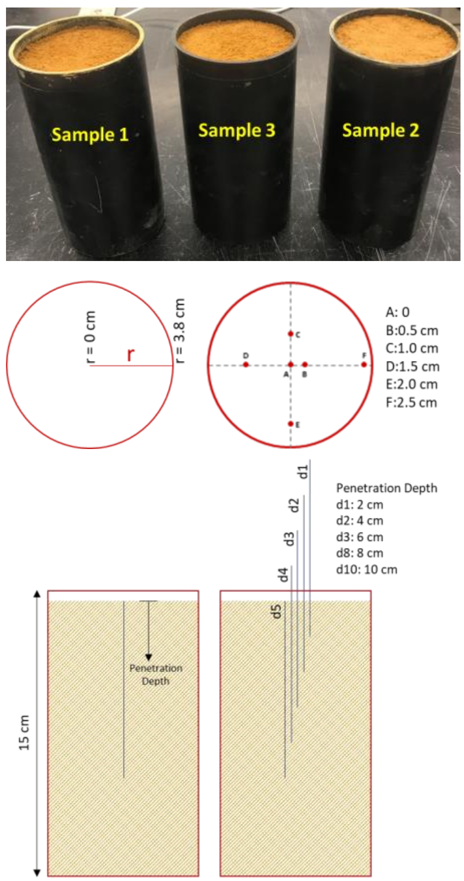


Figure 5. The layout of the thermal conductivity test.

We tested the thermal conductivity coefficients of different soil samples at different depths and distances from the center as shown in **Figure 5**, and then got the results as shown in **Figure 6**. These data would be inputted into the mobile game. When the players put the thermal conductivity meter at different positions of the sample, they can read the thermal conductivity of the soil (*k* value) from the screen shown in **Figure 7**. The thermal conductivity coefficient measured in this test can be used in the following FEM simulation of thermal piles.

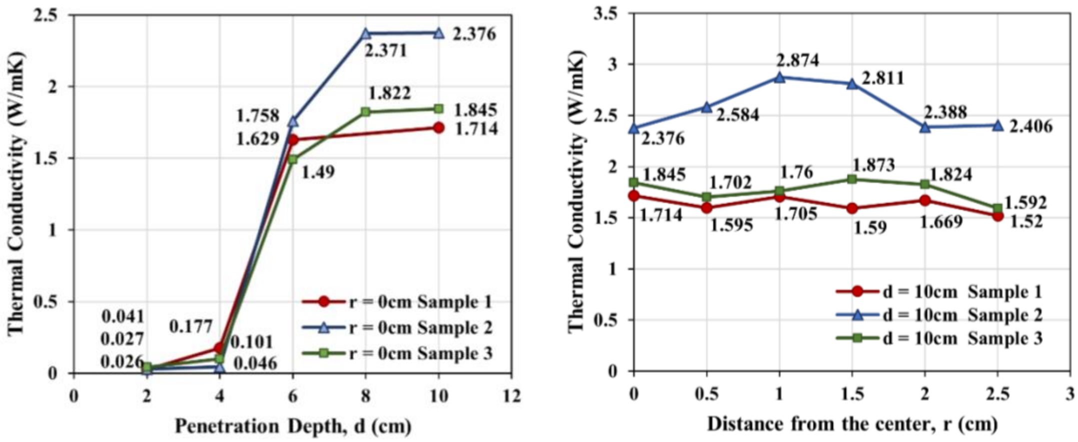


Figure 6. Thermal conductivity coefficients of different samples at different depths and distances from the center.

Figure 7. The thermal conductivity coefficient measured in a virtual test.

The second test is the direct shear test which is used to determine the shear strength of soils. The shear strength denotes the maximum resistance of soil to shearing. In the shear test, the normal pressure was applied to simulate the loading above the soil, and then the shearing force was applied between the top and bottom parts of the shear box. A simplified procedure was created to help the players take the test as accurately as possible. At first, the players must put the apparatus seen in **Figure 8** on an even surface. Then, they need to prepare the soil sample for the shear test, and turn on the apparatus by those buttons on the panel. After that, the shear test results will be displayed on the screen and saved on a local device.

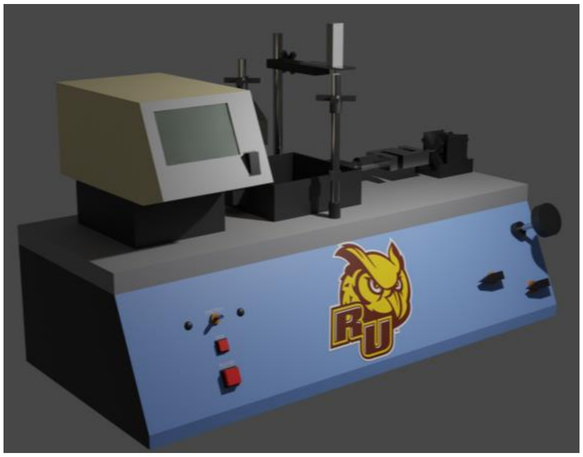


Figure 8. The shear test device.

Finite Element Method Simulation of Geothermal Piles

Geothermal piles contain a series of pipes built within the concrete pile, which can meet both loading-carrying capacity and energy extraction (Lyu et al. 2020). Typically, during the summer, the temperature below the surface is lower than above, and during the winter, it is higher than the surface. These piles can effectively heat and cool the building because their temperature is steadier compared with the outside temperature. In the long run, this helps the building save money.

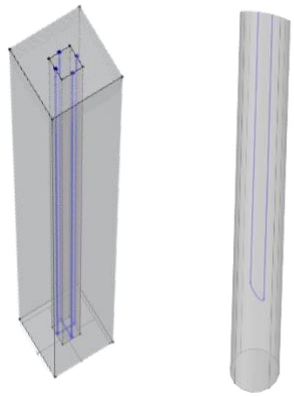


Figure 9. Different shapes of pipes and pile in COMSOL simulation.

Numerical simulation is an effective tool for geotechnical engineers. However, it is difficult to learn for undergraduate students. Therefore, we simplified the numerical simulation process in this mobile game. The numerical project will run through a virtual desktop, which allows the players to change some parameters of numerical simulation in mobile game and see the numerical results directly on mobile. The heat exchange process in the geothermal piles is simulated using the FEM (finite element method) program, COMSOL. The player can change the shape of pipes and concrete piles as shown in Figure 9, temperature gradient of ground, and water temperature to get different simulation results, which would be helpful for players to understand the mechanism of geothermal piles. Since geothermal piles hold great promise for future structures that are trying to develop utilizing green technologies, it is a good idea to incorporate these as a viable option in our game as more information about them becomes available.

CONCLUSION

In conclusion, the game's various modules have been carefully created to make sure that playing it is both educationally worthwhile and entertaining enough. Now we have conducted enough laboratory tests and numerical simulations, and got the required data for this mobile game. The study team will complete this mobile game by inputting laboratory data into virtual tests, and then plan its preliminary testing in the following academic year. This geotechnical game is expected to rise students' interest in geotechnical stud and help them seek a career in the geotechnical field with a virtual and engaging tool of learning.

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