Mixed Reality Game for Active Geotechnical Engineering Learning

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. This work allows students to learn the design of geothermal pile in a more inclusive way while playing a game and gain an "integrated geotechnical learning experience". Several mini games are designed for students to enhance the geotechnical knowledge. Players can earn points and update their appearance by playing these mini games, 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 and Background:

Recent challenges spurred on by population increase [1], major world events [2], urbanization [3], and climate change [4] have raised a pressing need for greater education and outreach for future geotechnical engineers. However, to tackle these expanding challenges, students need a broader range of knowledge than is typically provided in standard geotechnical engineering courses. Specifically, students are often not extensively educated in soil mechanics, a core concept in geotechnical engineering, with few opportunities to apply their knowledge through experimental and laboratory work [5-7]. As a result, not only is education lacking, but students often see the work as uninteresting or challenging, threatening outreach to gather new students and workers in the field [8].

The MERGE platform is inspired by popular mixed reality games, allowing students to see computer-generated models superimposed into the world through the camera on their mobile device. Building on recent advancements in cyberinfrastructure, MERGE is meant to provide an attractive and motivating environment to support students' geotechnical engineering skills. Throughout gameplay, students' strategic thinking will be tested through carefully designed games that relate to geotechnical problems. Additionally, the game uses their GPS to create a map of the real world around them, giving players the ability to explore their local environment to advance their game progress. Initial gameplay mainly focuses on a lab assignment involved with the design and analysis of geothermal piles which are special foundations that utilize the earth's temperature to heat and cool the associated building.

Our project, MERGE, focuses on improving and enhancing education for geotechnical engineering students, specifically in the area of soil mechanics and other basic concepts. Our goal is to provide a fulfilling learning experience while keeping the students engaged in a fun game. By allowing students to interact with mixed reality representations of lab and field work, they can engage in a continuous learning experience outside of the classroom without the need for lab access or expensive equipment. Using mixed reality technology, the game can both improve students' motivations to learn outside of the game environment [9] and provide additional insights into geotechnical principles through intuitive simulations and models [10]. The full game system also further stimulates students' learning by offering them unprecedented access to and availability of learning resources. By delivering educational content through this virtual game paradigm, we also hope to engage students in the learning process while allowing them to complete highly educational and enjoyable project work, seamlessly integrated with fun game environments.

Game Overview and Design:

Inspired by the mixed reality game, "Pokémon GO" [11], our mobile game includes a main storyline "quest" along with mini games; both of which will have educational twists. These will expose the players to situations and the real-life steps an engineer would go about to solve the problems. Geotech Game consists of two main game experiments: *Thermal Conductivity Test* and *Shear Stress Test*, each with several unlockable mini games, all of which will teach students different skills and aspects of the field. These skills include understanding soil levels, thermal conductivity, tools available, and more. A player begins the game on the map with two minigames unlocked. With the understanding and necessary tools collected, the game then leads the player to the first experiment - *Thermal Conductivity Test*. The same process is repeated for the second lab experiment *Direct Shear Test* and associated minigames, allowing the player to progress at their own pace through the material. After these two experiments, one finite element method (FEM) simulation of thermal piles is prepared for players to explore the mechanism of thermal piles. In this simulation, players can use the thermal conductivity coefficient measured in thermal conductivity test as an input parameter and build the thermal piles numerical model. Through changing the length of piles, the shape of pipes, and temperature of ground etc., different numerical results will be shown to players, which helps students learn about how these parameters influence the efficiency of heat extraction in thermal piles.

Module 1 - Choosing Avatar:

This module focuses on the creation of your avatar which will walk the map in the main game. Similar to the avatar in "Pokémon Go", this avatar will represent where the user is in the virtual world and will follow your path as you walk to collect the different tools, mini games, and activities.

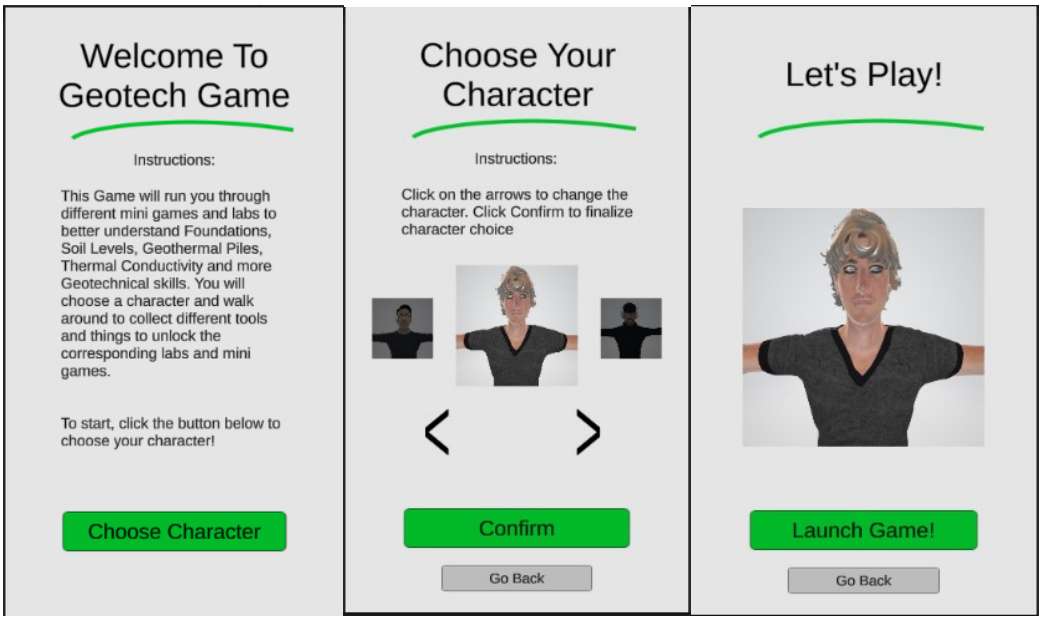

Figure 1: Directions Opening Page

Figure 1(a) shows the opening page when the application is first installed. This page is essential to give new users a full understanding of what they will be doing and how they can start by choosing their character. Figure 1(b) shows how users will choose the character they want to represent them in the main game. Within this, it was essential that there was representation for all cultures. Figure 1(c) shows a launch page where you can start the game in which the main storyline will launch and you will see your character in the map.

Module 2 - Main Game Map:

This module focuses on the main game interface which connects all the lab activities, mini games, and collectable items together along with the player displayed on the map. With the help of the mapbox API, we use the phone's GPS location to give users the experience of viewing their local area. They can rotate and zoom in and out around the map to find components they need to collect for other objectives.

Figure 2: Example map

The Pokemon Go style map as seen in figure 2 is the home screen of the game. This is where the player will see themselves and be able to interact with things around them and engage in minigames and lab equipment.

Module 3 - Mini Games:

For the mini games, the player would play word searches, a dig dug styled game, spot the difference, connect the dots and a snake game. The word search is the first game that the players can interact with. It is intended to provide background info on the geotechnical tools and vocab they will use while playing the rest of the game. The definition of the word will be displayed when the word is found. The Dig Dug game is inspired by the 1980's game dig dug where the player collects soil samples as they dig below the surface. Once they collect a certain amount to fill their meter they win. The player must avoid enemies in the meantime. In Spot the difference we would show the physical lab equipment with some key components missing in each photo that the player has to determine. In the Snake Game, the player must move through the ground collecting soil (while expanding) and avoiding other types of soil that aren't needed. Finally, in Connect the Dots game, the player will trace the dots in order to reveal a picture related to the experiment being performed. These mini games will work with a reward point system in order for the player to gradually gain points. These points can be earned and collected so that the player can use them as a form of in-game currency. They can change their clothes or make certain upgrades with these points.

Module 4 - Experiments:

The geotechnical experiments being conducted through this mobile game are a Thermal Conductivity Test and Direct Shear Test.

Thermal Conductivity Test

There are two experiments chosen for the players to construct. First is the thermal conductivity test. The thermal conductivity test determines how well a material conducts heat under steady state conditions. This is important because it is needed when creating a design of underground power transmission systems. This lab is simulated through virtual reality.

Figure 3: Thermal Conductivity Meter

The player is directed into a new screen where they will be in a temperature-controllable chamber. In front of them is the thermal conductivity device, as seen in figure 3, and multiple cylinders containing the sample soil. We want the player to be able to make mistakes as they look for the right fit. Once they choose the right sample, they would click on a spot in the soil to insert the probe. The ideal spot is directly in the center however the player will have unlimited chances to discover that. Once the probe is fully inserted into the soil, the player has to click the blue button in figure 3. The blue button then would determine the temperature of the sample in Celsius. After the temperature is determined, the *k* value (thermal conductivity coefficient) will appear, and the player has concluded the experiment. The thermal conductivity coefficient measured in this test can be used in the following FEM simulation of thermal piles.

Direct Shear Test

The next experiment is direct shear test, an experimental procedure conducted in geotechnical engineering that aims to determine the shear strength of soil materials. Shear strength is defined as the maximum resistance that a material can withstand when subjected to shearing.

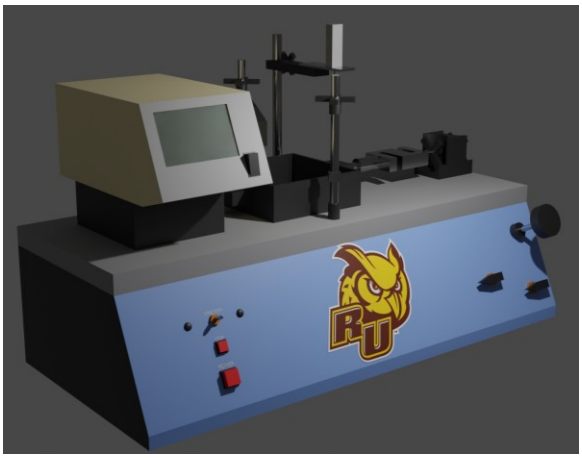

Figure 4: Shear Test Device

In the test, shear was applied between the top and bottom parts of the shear box. The normal stress or the downward pressure simulates the loading above the soil. The player will follow a simplified procedure to simulate in-person lab test as accurately as possible. First the player must make sure the apparatus seen in figure 4 is on an even surface. Then they must follow the standard procedure to prepare the assembly of the shear box for soil shear test. The player can turn the apparatus on and perform the test by controlling those buttons on the panel. Results will be displayed on the digital screen and saved to a local device.

Module 5 – FEM simulation:

Geothermal piles consist of a series of pipes that are built within a concrete pile, which can meet both loading-carrying capacity and the energy extraction [14]. Several meters below the earth's surface the temperature remains relatively constant all year long. The temperature below the surface is typically cooler than the weather outside during the summer and warmer than the surface during the winter months. Since the temperature of these piles remains constant in comparison to the weather outside it helps heat/cool the building efficiently. This helps the building save money in the long run. The main downside with geothermal piles is their high cost and the limited amount of tested data on the piles themselves. The geothermal piles are connected to a pump system that helps the liquid flow through the pipe network. The pipes embedded in concrete pile can take multiple different shapes including spiral, U, and UU shapes. The FEM (finite element method) software, COMSOL, is used to simulate the heat exchange process in geothermal pile. The player can change the shape of pipes and concrete piles, 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. As further information is learned about geothermal piles, it is a good idea to add these as a potential option in our game since it has high promise for future buildings that are looking to build using green technologies.

Conclusion:

To conclude, different modules in the game have been carefully developed to ensure playing the game is educationally beneficial but also fun enough. The research team has made significant progress and will plan its preliminary testing in the following academic year. Geotech Game is expected to provide students seeking a career in the geotechnical field with a virtual and fun way of learning.

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