Creative Geotechnical Engineering Education Module Based on an Educational Game Using Multiphysics Enriched Mixed Reality

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***Abstract*—This work-in-progress paper discusses the development of an educational game to provide integrated geotechnical engineering education modules that connect theoretical concepts, laboratory testing, field investigation, and engineering design. The game, *Earth Trek*, is developed based on the design of geothermal piles, which are an innovative and sustainable geotechnical engineering approach to combat climate change. Virtual reality is applied to visualize the field environments, laboratory conditions, and design components for structural simulation. The game uses a combination of storytelling and tasks to engage students with geotechnical concepts in an enjoyable way. With the newly developed game, geotechnical engineering instructors can provide students with exposure to laboratory testing and field environments, improving the quality of geotechnical engineering education. The use of multiphysics enriched mixed reality gaming allows for a visual representation of the connections between theoretical concepts, laboratory testing, field investigation, and engineering design.**

Additionally, this study discusses the challenges that geotechnical students face when dealing with worldwide concerns such as energy demand, environmental protection, infrastructure sustainability, and hazard reduction. *Earth Trek* allows students to apply geotechnical engineering knowledge to explore the underground space and the associated geothermal energy to tackle the engineering problems using only their smartphones. Through exploring the virtual environment and completing game tasks, students can obtain different testing tools used for geotechnical experiments, including thermal conductivity measurement and direct shear test. They are also trained to conduct parametric study to explore the influence of boundary conditions on thermal transfer efficiency of the geothermal pile. The key contribution of this work is to illustrate an educational paradigm based on mixed reality, moving towards creative engineering education in geotechnical engineering. The newly developed educational game and Earth Trek are expected to enhance geotechnical engineering education and provide students with an interdisciplinary knowledge to tackle worldwide concerns.

***Index Terms*—Engineering education, gamification, mixed reality, multiphysics, simulation**

I. Introduction

Geotechnical engineering is a broad discipline that utilizes the principles of soil mechanics and rock mechanics to build infrastructure on the most challenging natural materials [1]. However, traditional geotechnical engineering education is often limited by the lack of connection among different subjects such as soil mechanics, foundation engineering, structural design, and numerical simulations. This lack of connections hinders the ability of students to gain a comprehensive understanding of interdisciplinary studies and creative problem-solving skills. To address this issue, game-based learning has been proposed as a teaching aid to stimulate the engineering creativity of geotechnical students [2].

Earth Trek transforms the design process of a geothermal pile into an educational game, stimulating the engineering creativity and problem-solving ability of geotechnical engineering students. Within *Earth Trek*, students are tasked with the engineering project of constructing geothermal piles. As they explore the environment and complete tasks, students interact with engaging story-telling activities and interactive tasks to gain interdisciplinary knowledge and game scores [3] to encourage learning.

The design of geothermal piles is particularly suitable as an underlying story for the educational game as it provides an innovative and sustainable solution to the global issue of climate change. *Earth Trek* shows students the role of geotechnical engineers in solving global issues [4], enhancing their sense of pride and stimulating them to pursue their careers in geotechnical engineering. The game also integrates all the contents of geotechnical engineering education in an engaging way, encouraging students to consider the mechanical and thermal properties of geomaterials when designing a

geothermal pile.

II. GAME THEME AND DESIGN

The development of *Earth Trek* is inspired by recent educational successes in using mixed reality to enhance learning [5]. Outside of education, *Earth Trek* also takes inspiration from the well-known hybrid game *Pokémon GO* [6]. This game uses real-time geolocation to generate wild creatures around the player for capture while providing encouragement for players to move around and visit new locations. Ultimately, *Earth Trek* seeks to achieve similar goals, in that it both engages the player in an exciting virtual world and allows the player to actively participate in the game by moving in the real world.

Our game also includes a map and a main story mission, containing two mini-games and two main experiments. As the game's story progresses, players will be exposed to the same work steps as in reality, starting from the beginning to elicit geotechnical engineering problems and leading them step by step to obtain tools to investigate the site at a designated location in the real world. Soil samples are collected in-game and thermal conductivity and direct shear tests are completed in the in-game lab. The process of the game allows players to learn about soil moisture, thermal conductivity, and the use of laboratory apparatus, all without requiring access to physical lab spaces and equipment. This saves time and space resources, as actual field investigations and laboratory experiments require a significant amount of preparation and management work.

Fig. 1 shows both the start screen (left) and the introduction (right) to *Earth Trek*. If students have any questions about the subsequent operation, they can browse the tutorial of the game by selecting the "Guide" button. When selecting a character, as in Fig. 2 (left), the virtual avatar of Professor Olivia will appear. As the game's non-player character (NPC), she will guide the player through the mini-games and experiments. Once the game starts, the player's chosen character will come to the large map as in Figure Fig. 2 (right). Using the Mapbox library, players are shown a map of the surrounding area using their real world location. Players can then locate suitable sites to take soil samples by exploring around the local area.

To help gamify the learning process, students play through various mini-games that help to break up the educational content. Fig. 3 shows the two mini-games currently implemented: Digdug (left) and Connect the Dots (right). The Digdug mini-game takes inspiration from a popular classic game of the same name, tasking players with controlling a drill to collect soil samples while avoiding obstacles. As players dig deeper, they also learn about soil layers, since the drill has more difficulty moving through deeper soil layers, similar to real-world soil drilling. Connect the dots, meanwhile, instructs students on the uses and appearance of the various tools that are needed for geotechnical engineering.

Beyond the mini-games, *Earth Trek* has students undergo two geotechnical engineering experiments showin in Fig. 4: A thermal conductivity test (top) and a direct shear test (bottom). In the thermal conductivity experiment, shown in Fig. 5, students are tasked with measuring the soil at both different depths (top) and different locations (bottom). Like a real lab experiment, students are encouraged to explore different locations to determine which location gets optimal measurements. Additionally, the operating interface of the testing apparatus is the same as the actual one, as the virtual environment and game interface are meant to be a substitute for a real-world lab experiment. As students take their measurements, the game automatically records their results and helps them reach certain

Fig. 1. The interactive interface of *Earth Trek*, showing the title screen (left) and the introduction page (right).

Fig. 2. Additional interfaces in *Earth Trek*, showing the character selection screen and introduction to Professor Olivia (left) and the world map (right).

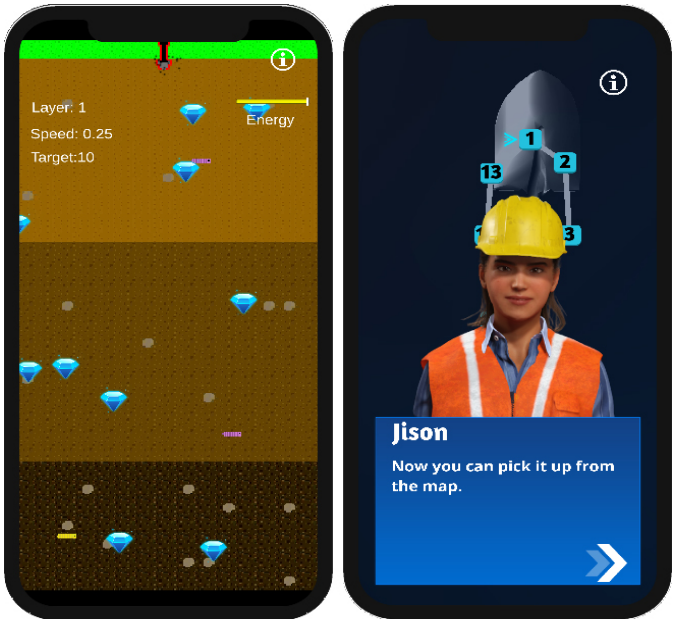

Fig. 3. The mini-games currently implemented in *Earth Trek*, showing Digdug (left) and Connect the Dots (right).

conclusions about soil measurement and soil properties. In the direct shear test, students will test additional properties of the soil using a new set of equipment.

Fig. 4. Interactive lab experiments in *Earth Trek*, showing the thermal conductivity test (top) and the direct shear test (bottom).

To further improve the educational value of the game, *Earth Trek* implements some interactive teaching elements. For example, Professor Olivia provides timely feedback and guidance on the player's game progress and experiment results. In addition, there are quizzes and question-and-answer sessions in the game that allow players to review and consolidate what they have learned, as shown in Fig. 6.

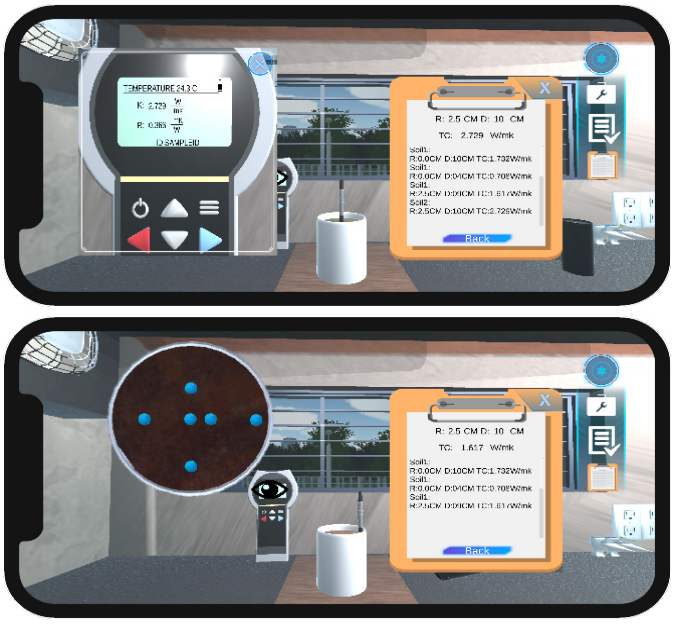

Fig. 5. Experiment in Earth Trek: (Top) different depths and (Down) different locations

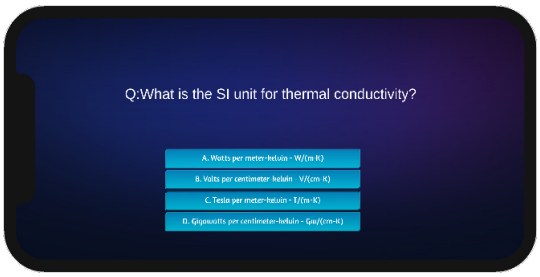

Fig. 6. The test question interface in *Earth Trek*.

III. Game Test Results

To test the game's educational utility, we invited 28 undergraduate students from the Department of Civil Engineering at Rowan University to participate in the test. These students were given 11 test questions before and after completing the thermal conductivity experiment in order to analyze the results. As shown in Fig. 7, the dashed line indicates the average score. It can be seen from the figure that the mean scores of the participants were low before the game experiment, while they increased after the game experiment. In addition, 9 out of 13 participants got all the questions correct, a result that further supports the effectiveness of the game and shows that this educational game can help to improve the knowledge and skills of the participants.

The analysis of the heat map also allowed us to further understand which questions were more difficult for the participants in the experiment and which questions were relatively easier to master. Fig. 8 shows the distribution of answers before and after the virtual experiment, respectively. Before

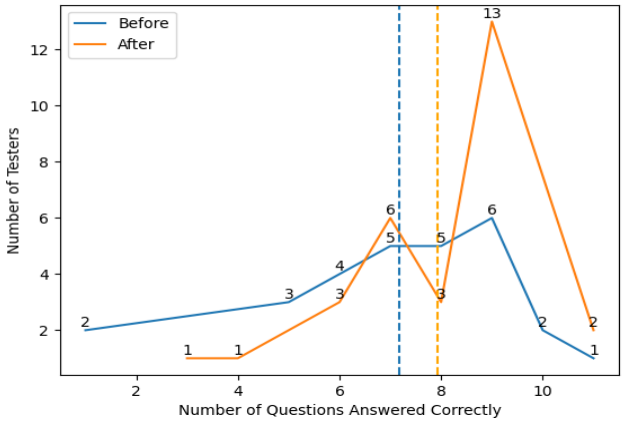

Fig. 7. Student performance on content tests before and after playing *Earth Trek*.

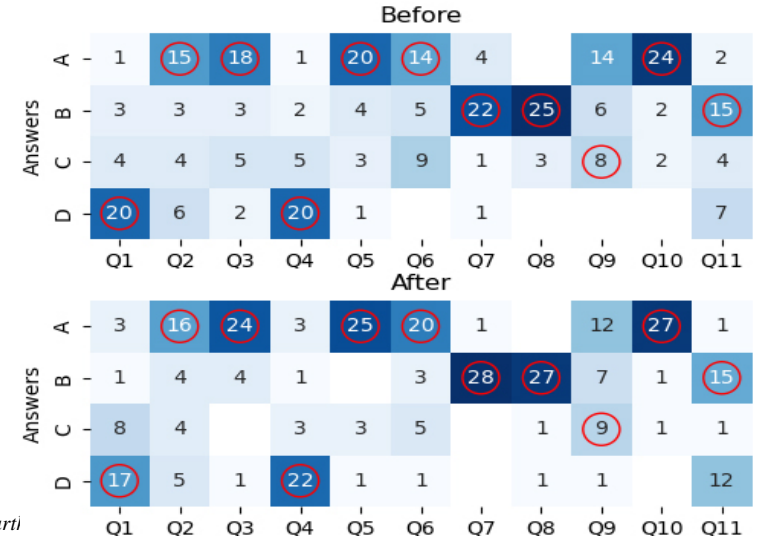

Fig. 8. Heat map showing the distribution of student answers on each question, with the correct answer circled in red.

the virtual experiment, many participants failed to choose the correct answers to certain questions, such as Q6 and Q9, while after the virtual experiment, the number of participants who chose the correct answers increased significantly. This indicates that teaching the game can indeed improve participants' mastery of knowledge points and enable them to better select the correct answers.

These student results are an important reference value for us to optimize the teaching design of the game and improve the educational content. If certain knowledge points were answered incorrectly by most participants, we can consider adding explanations of relevant knowledge points or providing more practice opportunities in the game to help participants master these knowledge points better. If certain knowledge points are mastered to a higher degree, we can consider adding more high-level knowledge points or more application scenarios in the game to challenge the participants and further improve their learning effect. We can identify the shortcomings in the game design and make improvements based on the comparative analysis of the test results. If the test results show a high failure rate for certain questions, we can analyze whether there are difficult-to-understand game rules in the game design or whether the game operation is simple and easy to understand, and ultimately optimize and improve the game.

IV. CONCLUSION

In conclusion, this paper presents the results from the ongoing development of *Earth Trek*, an educational game for geotechnical engineering. By implementing this game in a classroom setting, we hope to improve student education while simultaneously making classroom learning more fun for students. Out testing results support our initial hypothesis that the game encourages educational success. Additionally, due to the virtual nature of the game, students can perform complex lab experiments without needing access to physical lab spaces and equipment, allowing a wider range of students to access experiments at their own convenience. Ultimately, future work will focus on continuing to update and improve the game environment and educational content to make a more enjoyable and educationally valuable experience for students.

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