Paper ID #40817

Enhancing Geotechnical Engineering Education Based on Multiphysics Enriched Mixed Reality Game

Mr. Chenchen Huang, Rowan University

I'm a Research Assistant of Civil and Environmental Engineering Department of Rowan University now. I mainly research rock mechanism problems and pavement design issues by numerical simulation.

Weiling Cai

Mr. Weiling Cai is a PhD student in Civil Engineering at Rowan University. His research interest involves multi-scale characterization of geomaterials, geotechnology, and constitutive modelling.

LuoBin Cui, Rowan University

program

Prof. Cheng Zhu, Rowan University

Dr. Cheng Zhu is an assistant professor of civil engineering at Rowan University. His research primarily concerns multi-scale geomaterial behavior under coupled processes across various time scales, with emphasis placed on microstructure characterization,

Dr. Ying Tang, Rowan University

Ying Tang received the B.S. and M.S. degrees from the Northeastern University, P. R. China, in 1996 and 1998, respectively, and Ph.D degree from New Jersey Institute of Technology, Newark, NJ, in 2001. She is currently a Professor of Electrical and Comput

Enhancing Geotechnical Engineering Education Based on Multiphysics Enriched Mixed Reality Game

Chenchen Huang, M.S.[1]; Weiling Cai, B.S.[2]; Luobin Cui, M.S.[3]; Cheng Zhu, Ph.D., P.E.[4]; and Ying Tang, Ph.D., P.E.[5]

[1]Department of Civil and Environmental Engineering, Rowan University, 201 Mullica Hill Road, Glassboro, NJ 08028; E-mail: huangc57@students.rowan.edu
2Department of Civil and Environmental Engineering, Rowan University, 201 Mullica Hill Road, Glassboro, NJ 08028; E-mail: caiwei58@students.rowan.edu
[3]Department of Electrical and Computer Engineering, Rowan University, 201 Mullica Hill Road, Glassboro, NJ 08028; E-mail: cuiluo77@students.rowan.edu
[4]Department of Civil and Environmental Engineering, Rowan University, 201 Mullica Hill Road, Glassboro, NJ 08028; E-mail: zhuc@rowan.edu
[5]Department of Electrical and Computer Engineering, Rowan University, 201 Mullica Hill Road, Glassboro, NJ 08028; E-mail: tang@rowan.edu

ABSTRACT

This study introduces the development of the multiphysics enriched mixed reality for integrated geotechnical education (MERGE) platform. This platform combines geotechnical learning with visualization, collaboration, and numerical simulation. To stimulate engineering creativity and study interest of students, the gameplay is story-based and task-based. Through exploring the virtual environment and finishing game tasks, students can obtain different testing tools used for geotechnical experiments (e.g., thermal conductivity measurement and direct shear test). Students can be trained from these laboratory experiments to have a better understanding of fundamental soil mechanics principles (e.g., thermal conductivity and shear strength of soil). Thereafter, the measured geotechnical properties are used as input parameters in the finite element method (FEM) simulation of geothermal piles. Furthermore, several mini-games (e.g., word searches, dig dug, spot difference, connect dots, and snake game) have been designed to provide background information and encourage students to play this game. This platform has been tested by students and has received feedback from students this semester. The key contribution of this work is to illustrate an educational paradigm based on the mixed reality: toward creative engineering education in geotechnical engineering.

INTRODUCTION

To deal with increasing global concerns, including energy demand, environmental protection, infrastructure sustainability, and geohazard mitigation, next-generation geotechnical engineers are required to be capable of identifying, preventing, and solving such emerging multi-physical geotechnical problems. Therefore, geotechnical engineering students are expected to acquire a wider range of knowledge of the underlying science and governing mechanisms than was previously covered in a traditional geotechnical course. Possessing an integrated background of knowledge is crucial for the future geotechnical workforce. However, it is challenging for students to master the comprehensive framework (i.e., theoretical concepts, laboratory testing, and engineering design) in traditional geotechnical engineering education.

Many students find geotechnical engineering education to be disconnected from their interests and career aspirations, leading them to perceive geotechnical jobs as tedious, challenging, and irrelevant. As a result, current geotechnical engineering education often fails to establish a strong interaction with students[1, 2]. To overcome these challenges and raise students' interest in geotechnical engineering, traditional group projects in geotechnical engineering courses are being replaced with creative, project-based participation games, such as mixed reality games, to illustrate engineering principles using real-world applications. Based on Cone Penetration Testing (CPT) results, Bennett, Harteveld [3] developed a mixed reality game for geotechnical students and found that the learning interest and efficiency of students had been significantly enhanced. The interactive animations and virtual (game-based) geotechnical laboratory tests proposed by Budhu [4] considerably improved the presentation of important concepts, student learning, and retention. Students will be inspired to develop abilities to handle difficult geotechnical issues by themselves in this competitive and enjoyable gaming setting.

Therefore, to improve student education in the context of geotechnical engineering, a multiphysics enriched mixed reality for integrated geotechnical education (MERGE) platform is developed in this study. Based on the geothermal pile design, a story-based and task-based geotechnical game combining serval mini-games and geotechnical tests is designed in this study to help students master the processes of geotechnical tests (thermal conductivity test and direct shear test of soil) and geothermal pile design.

METHODOLOGY

This platform provides students the virtual reality (VR) technology overlaid in the real environment using the camera on their mobile smartphones. Based on the GPS function on smartphones, students can access the map of the actual world around them on the MERGE platform. It can visualize the field environments (e.g., geomaterial sample and underground condition), laboratory conditions (e.g., geotechnical testing tools and devices), and numerical simulation for the structural design of the geothermal pile. Fig. 1 shows the virtual area at Rowan University. Students are allowed to click the mounds shown on the map to collect different soil samples for the following laboratory tests.

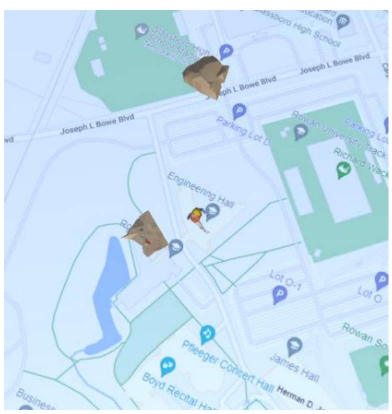


Fig 1. Game map around Rowan University.

Fig. 2 shows the scheme of the integrated geotechnical education module for a geothermal pile design. To achieve the geothermal pile design, several laboratory tests are required to get the input parameters (e.g., thermal conductivity coefficient and direct shear strength) of soils. In traditional geotechnical education, undergraduate students have limited chances to access such laboratory tests. The MERGE platform embeds two laboratory tests (thermal conductivity test and direct shear test) to help students to be familiar with the processes of these two laboratory tests and get the input parameters for the following geothermal pile design. Thereafter, a FEM (Finite Element Method) numerical simulation of geothermal piles is designed in this MERGE platform. Students are allowed to use the trial-and-error method to design various geothermal pile structures, which provides an opportunity to access FEM simulation and stimulates the engineering creativity of students. In addition, a series of learning-based mini-games are designed to give background knowledge and interest students to play the full game. More details about the different modules of this game are introduced in the following sections.

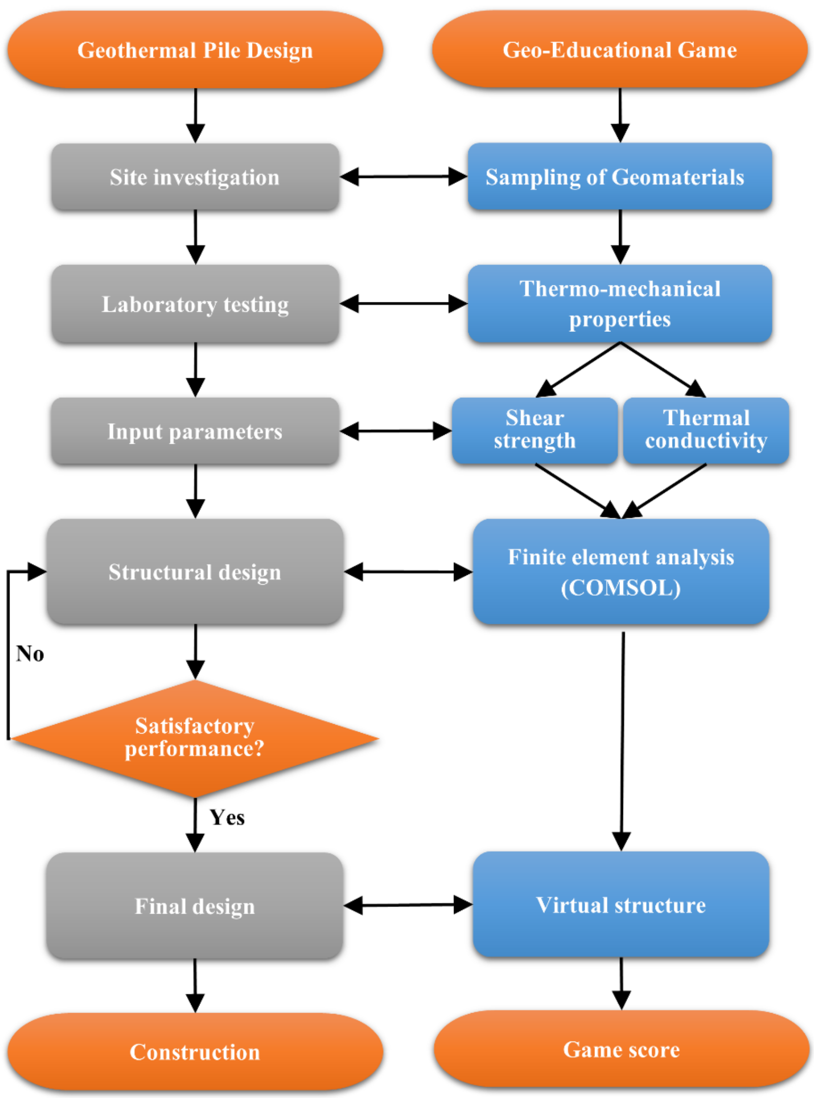
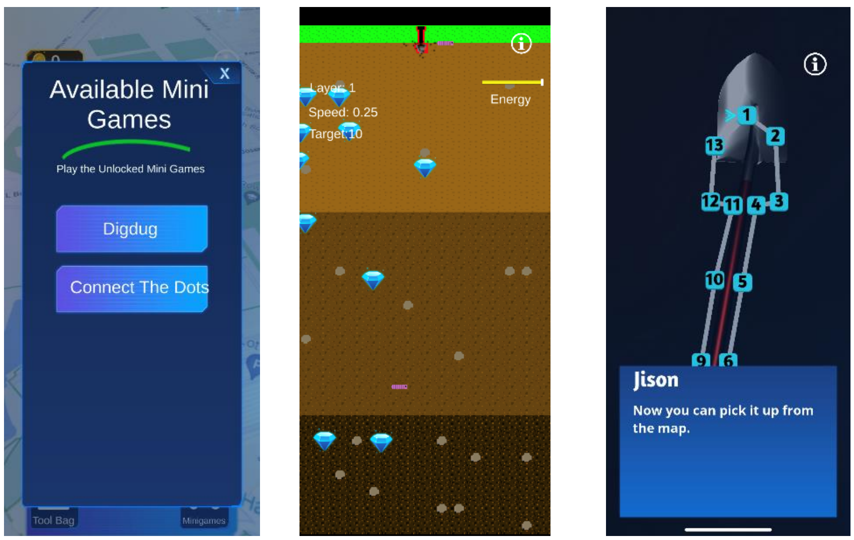


Fig 2. A scheme of the integrated geotechnical education module.

Mini-Game Development

Several learning-based mini-games (e.g., word search, connect the dots, spot the difference, and dig dug games) are developed to give background knowledge and context on the concepts and tools that players would require when playing the main game. Fig. 3(a) shows two available mini-games now: dig dug (Fig. 3(b)) and connect the dots (Fig. 3(c)). Through playing these mini-games, students can get some tools required for following laboratory tests. For example, as shown in Fig. 3(c), students can get a shovel after the players connected all dots in order. Furthermore, a point system is designed for students to encourage them to play this game. Students are rewarded with some points after some mini-games. They can use these points to alter their avatar, such as changing its clothes or making certain upgrades throughout the game.



(a) Mini games (b) Dig dug (c) Connect the dots

Fig 3. Mini-game designed in MERGE platform.

Thermal Conductivity Experiment

The thermal conductivity test is used to evaluate the thermal conductivity of various soils under steady-state conditions, which is critical for designing underground heat transfer systems. The thermal conductivity of three soil samples was tested at various depths and distances from the center, as illustrated in Fig. 4. Then the results of thermal conductivity experiments are shown in Fig. 5.

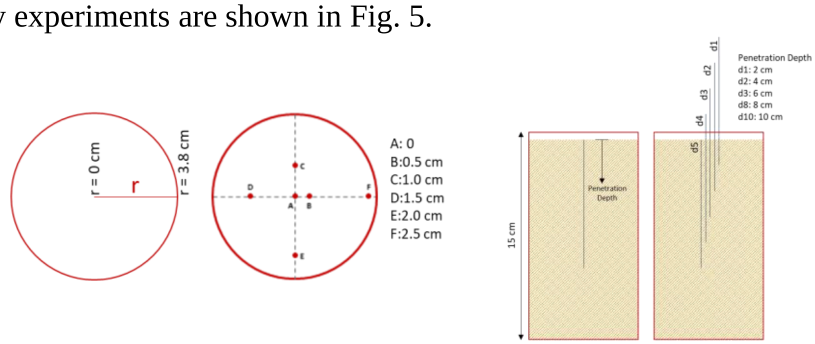


Fig 4. The layout of the thermal conductivity test.

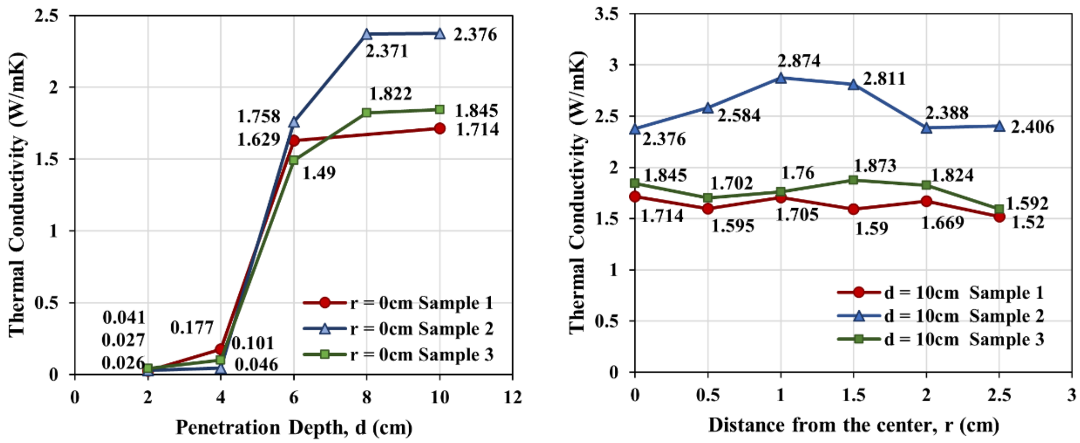


Fig 5. Thermal conductivity coefficients of different samples at different depths and distances from the center.

The experimental results have been inputted into the MERGE platform. When the students place the thermal conductivity meter in various places on the sample, the thermal conductivity of the soil (*k* value) can be read from the screen displayed in Fig. 6. The thermal conductivity coefficient determined in this test can be utilized in the following FEM modeling of thermal piles.

Fig 6. The thermal conductivity coefficient measured in a virtual test.

Direct Shear Test

The direct shear test, which is used to assess the shear strength of soils, is the second test. The maximal resistance of soil to shearing is indicated by the shear strength. In the shear test, the shearing force is delivered between the top and bottom halves of the shear box after the normal pressure is supplied to mimic loading above the soil. Water can be utilized to assist maintain a saturated state (like it would be under most structures) during a prolonged shear stress test. It replicates the loads above the earth as well as the regular tension or downward pressure.

The direct shear test is performed to obtain the strength characteristics (i.e., friction angle and cohesion) of the Mohr-Coulomb failure criteria as shown in Fig. 7 at first. Then the experimental results of the direct shear test are inputted into the MERGE platform, which allows students to study the direct shear test on their smartphones. The player can choose to enter the lab and choose an even place to begin erecting the shear box in this video game adaptation of a lab experiment. Students are expected to comprehend the stress-dilatancy relationship and apply the strength characteristics to estimate the bearing capacity of the geothermal pile [5].

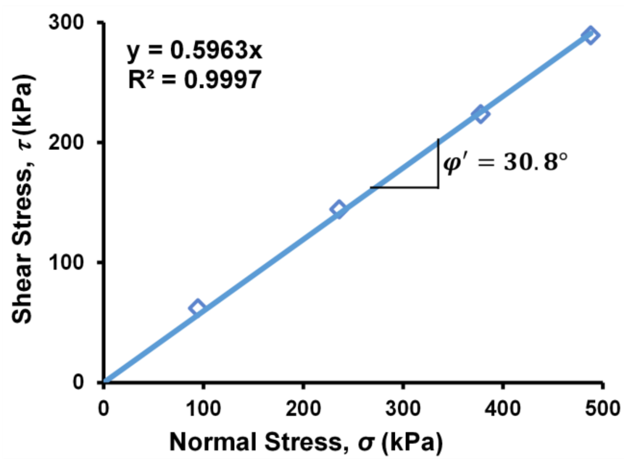


Fig 7. Laboratory direct shear testing of soil.

Fig. 8 shows the direct shear testing device built into the MERGE platform. For this device, the upper bracket must be lowered down such that the arm is over the top of the iron ball. All load and pressure knobs must be deactivated prior to the beginning of direct shear testing. Students can then activate the equipment by pressing the controller box button. The player can then vary the pressure by using the knob on the right. After that, the player can activate the selected load function and then apply loading. Finally, the player must hit the direction flip to the left for the apparatus to start moving. The results can then be obtained from the display screen on the top left of the apparatus.

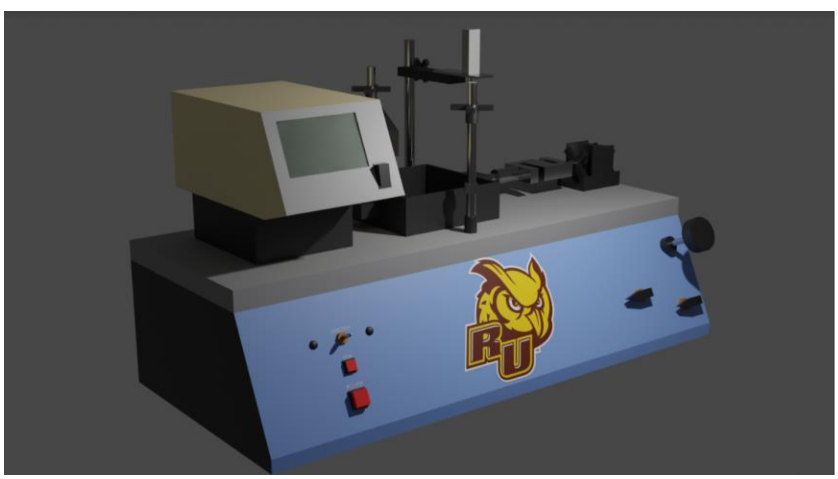


Fig 8. Example 3D model of the direct shear testing machine.

Geothermal Pile Simulation

Geothermal piles are concrete piles containing a series of pipes, which can meet the requirements for loading and energy extraction [6]. The pipes embedded in geothermal piles can extract heat from underground soil and provide energy for upper buildings, which helps the building save money in the long term.

Using the numerical simulation method can help us to better design the geothermal piles. However, undergraduate students might have few chances to access numerical simulation in traditional geotechnical engineering education. This MERGE platform offers an opportunity for students to learn about numerical simulation. The numerical project will be executed through a virtual desktop, allowing students to alter various numerical simulation settings in the mobile game and see the numerical outcomes immediately on mobile. COMSOL, a FEM tool, is used to simulate the heat exchange mechanism in geothermal piles. Fig. 9 shows the fluid velocity in a spiral pipe. Students are trained to conduct parametric studies to explore the influence of boundary conditions (e.g., thermal conductivity of soil, pile depth, pile shape, and fluid velocity) on the thermal transfer efficiency of the geothermal pile. Because geothermal piles offer tremendous potential for future constructions that are attempting to grow using green technology, it is a good idea to include them as a possible option in our game when more information becomes available.

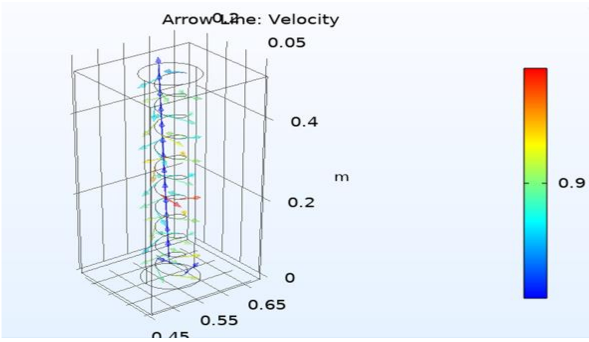


Fig 9. Fluid velocity in the spiral pipe.

SURVEY RESULTS

Eleven test questions are designed for students to test the MERGE platform as shown in Fig. 10. Students are required to take this knowledge test before and after playing the game. Two survey results are analyzed and compared as shown in Fig. 11. Prior to the experiment, the mean scores of the students who participated were very low, but after the experiment, the mean scores of the students who participated climbed dramatically. This outcome supports the experiment's validity and demonstrates that this instructional game may truly increase the participants' learning interest and knowledge. The analysis of answer distribution shown in Fig. 12 also allowed us to further understand which questions are more difficult for the participants in the experiment and which questions are relatively easier to master. Many participants failed to pick the correct answers to some questions prior to the experiment, but the number of participants who chose the correct answers increased following the trial. This suggests that the game can increase players' comprehension of the knowledge points and enable them to pick the correct answers more correctly. This is an important reference for us to optimize the teaching design of using the educational game.

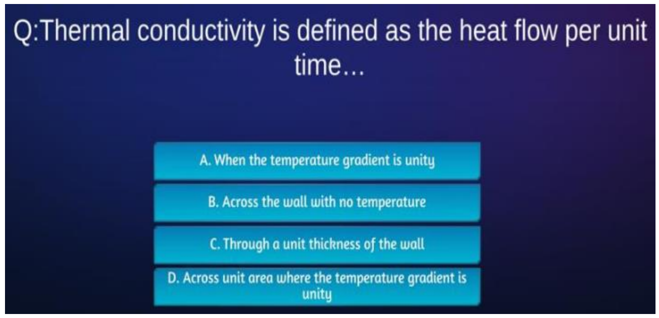


Fig 10. Example of knowledge test designed for students.

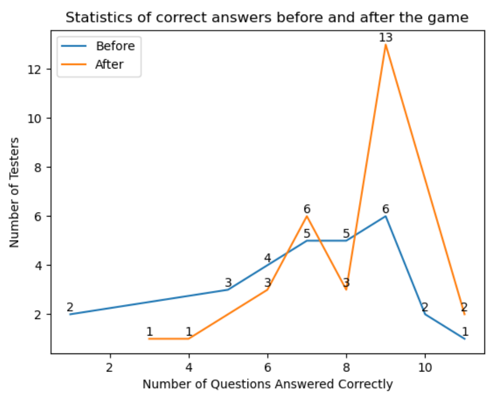
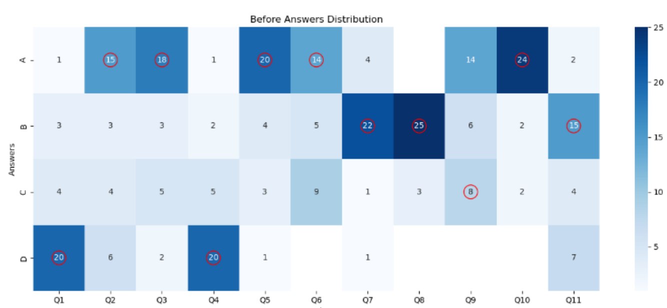
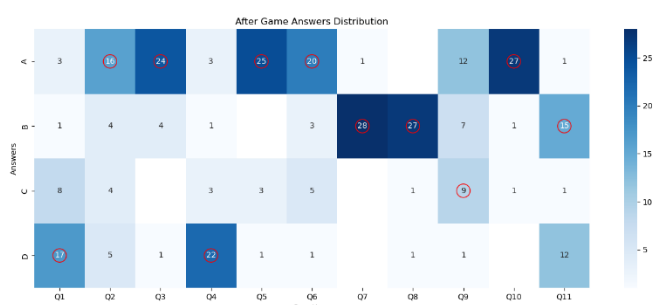


Fig 11. Statistics of correct answers before and after the game.



(a) Before game



(b) After Game

Fig 12. Answer distribution of knowledge test.

CONCLUSIONS AND FUTURE WORK

In conclusion, the game's modules have been carefully designed to ensure that playing it is both educationally valuable and interesting. We have completed sufficient laboratory testing and numerical simulations to obtain the necessary data for this mobile game. The virtual thermal conductivity test has been finished on the MERGE platform. The next step is to finish the virtual direct shear test and input laboratory test results into the MERGE platform. Thereafter, we will invite more students to test this game and get more helpful feedback from students. With a virtual and engaging learning tool, this geotechnical game is designed to increase students' interest in geotechnical studies and encourage them to pursue a career in the geotechnical profession.

ACKNOWLEDGEMENT

This work was supported by the National Science Foundation under grant number 2121277. We also gratefully acknowledge the financial support provided by the Center for Research and Education in Advanced Transportation Engineering Systems (CREATEs) at Rowan University.

REFERENCES

[1] Ferentinou, M. and Z. Simpson. *Action Research to Enhance Student Engagement in Geotechnical Engineering*. in *IAEG/AEG Annual Meeting Proceedings, San Francisco, California, 2018—Volume 6*. 2019. Springer.

[2] Shidlovskaya, A. and J. Briaud. *Modern syllabus for introduction to geotechnical engineering*. in *Proc., Int. Conf. Geoengineering Education, Shaping the Future of Geotechnical Education. Brazil: ABMS*. 2016.

[3] Bennett, V.G., et al. *Implementing and assessing a game-based module in geotechnical engineering education*. in *Geo-Congress 2020: Geotechnical Earthquake Engineering and Special Topics*. 2020. American Society of Civil Engineers Reston, VA.

[4] Budhu, M., *Interactive multimedia geotechnical engineering course*, in *Geotechnical Engineering Education and Training*. 2020, CRC Press. p. 329-333.

[5] Bolton, M.D. and C. Lau, *Vertical bearing capacity factors for circular and strip footings on Mohr–Coulomb soil.* Canadian Geotechnical Journal, 1993. 30(6): p. 1024-1033.

[6] Lyu, W., H. Pu, and J.N. Chen, *Thermal performance of an energy pile group with a deeply penetrating U-shaped heat exchanger.* Energies, 2020. 13(21): p. 5822.