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Board 211: An Educational Game Using Multiphysics Enriched Mixed Reality for Integrated Geotechnical Engineering Education

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An Educational Game using Multiphysics Enriched Mixed Reality for Integrated Geotechnical Engineering Education

ABSTRACT

Traditional geotechnical engineering education has difficulties for students to connect among theoretical concepts, laboratory testing, field investigation and engineering design due to the limitation of temporal and spatial resources. Developing an educational game could provide an integrated geotechnical engineering education so that students could systematically comprehend the process of a design for a geotechnical project from theories, experiments, and practical designs. To achieve this educational goal, this paper presents ongoing development of an educational game to propose an integrated geotechnical engineering education method by using multiphysics enriched mixed reality. The game is developed based on a design of geothermal piles which represent an innovative and sustainable geotechnical solution to the global climate change issue. Virtual reality is applied to visualize the field environments (e.g., geomaterials, ground conditions, and sampling), laboratory conditions (e.g., technician, testing devices, and tools), and design components for structural simulation (i.e., finite element software). The gameplay is story-based and task-driven to engage students with geotechnical concepts in a pleasant way. Several mini-games have been designed to provide background information and encourage students to play this game. This game includes soil sampling on the field, measuring thermomechanical properties of soils in the laboratory, and structural design and numerical simulation of a geothermal pile based on finite element method (FEM). Students will be led to use a thermal conductivity meter and direct shear device to obtain thermal conductivity and shear parameters for the collected soil samples. Thereafter, the associated properties are applied in the structural design of geothermal piles. This newly developed educational game allows geotechnical engineering instructors to expose students to more laboratory testing and field environments. The geotechnical engineering education could be enhanced by visualizing the inherent cohesion among theoretical concepts, laboratory testing, field investigation and engineering design through multiphysics enriched mixed reality gaming.

Introduction and Background:

Geotechnical engineering is a discipline of creative application based on principles of soil mechanics and rock mechanics. It determines that the geotechnical engineering education requires both engineering creativity stimulation and interdisciplinary study. Well trained geotechnical engineers are expected to creatively solve engineering problems for building various infrastructures using the most complicated natural materials (i.e., soil and rock). In fact, traditional geotechnical engineering education is often full of tedious formalization due to stereotyped design guidelines. Furthermore, the current engineering curriculum design generally lacks the connection/cohesion among different subjects (e.g., material mechanics, structural mechanics, hydraulic mechanics, soil mechanics) for geotechnical engineering education [1]. It hinders geotechnical students' ability to gain the comprehensive understanding of interdisciplinary study and further affects the ability of creative problem solving. To address this issue, game-based learning might provide an alternative approach to stimulate the engineering creativity of geotechnical students.

Creativity which is the essence of engineering can be neither explicitly taught nor trained in the traditional curriculum of geotechnical engineering [2, 3]. However, the engineering creativity can be simulated, according to the KPA theory (in which “K” stands for knowledge; “P” means processing; “A” represents attitude) [2]. The KPA theory suggests that creativity could be promoted by the combination of comprehensive knowledge, rigorous processing ability, and proper attitude/purpose. An educational game could achieve this by providing geotechnical students with the virtual circumstance that allows them to gain interdisciplinary knowledge in the story-based and task-driven gameplay. We, therefore, develop a multiphysics enriched mixed reality game for integrated geotechnical education (MERGE). The MERGE transforms the design process of a geothermal pile into ab educational game. The game simulates all the scenarios that might be involved in an engineering project such as constructing a geothermal pile, including field investigation, laboratory testing, design, and construction. The virtual circumstance is made by obeying basic physical laws. In the design of the geothermal pile, multiphysics (i.e., solid mechanics, fluid mechanics, and thermodynamics) are involved. The game shows student players the comprehensive knowledge that is required in engineering practices. The game is also full of story-telling activities to keep students engaged and provides an interactive task stimulating students to gain game scores. This guides students to develop a proper attitude/purpose for geotechnical infrastructure designs. While students are playing the game and attempting to gain game scores, their processing abilities can be trained.

We purposely choose the design of geothermal piles as the underlying story for the educational game. This is because this topic is an interdisciplinary study and provides an innovative and sustainable solution to the global issue of climate change [4]. Beyond the traditional teaching in geotechnical engineering, the MERGE platform can show students with the role of geotechnical engineers how to solve global issues. It could enhance the sense of pride for being geotechnical engineering students. The geothermal pile is known as an emerging technology that utilizes the underground geothermal energy for cooling or warming infrastructures through heat exchange. A geothermal pile generally consists of a pile foundation, a heat exchanger, and a heat pump [4]. The players are expected to consider the bearing capacity of a geothermal pile influenced by both mechanical and thermal loadings. That requires students to fully understand the mechanical and thermal properties of geomaterials. This is achieved by performing laboratory testing and numerical modelling in the virtual environment. The design of the geothermal pile is conducted on a widely-used software (i.e., COMSOL) for finite element method (FEM). The game integrates all contents in the geotechnical engineering education in a pleasant way.

Therefore, the proposed educational game is expected to achieve three educational goals: 1) To stimulate the engineering creativity and problem-solving ability of geotechnical students; 2) To equip students with a methodology of systematically developing a geotechnical project (i.e., geothermal pile); 3) To develop an educational paradigm for improving the learning experience and interest by using the teaching technique of mixed reality games.

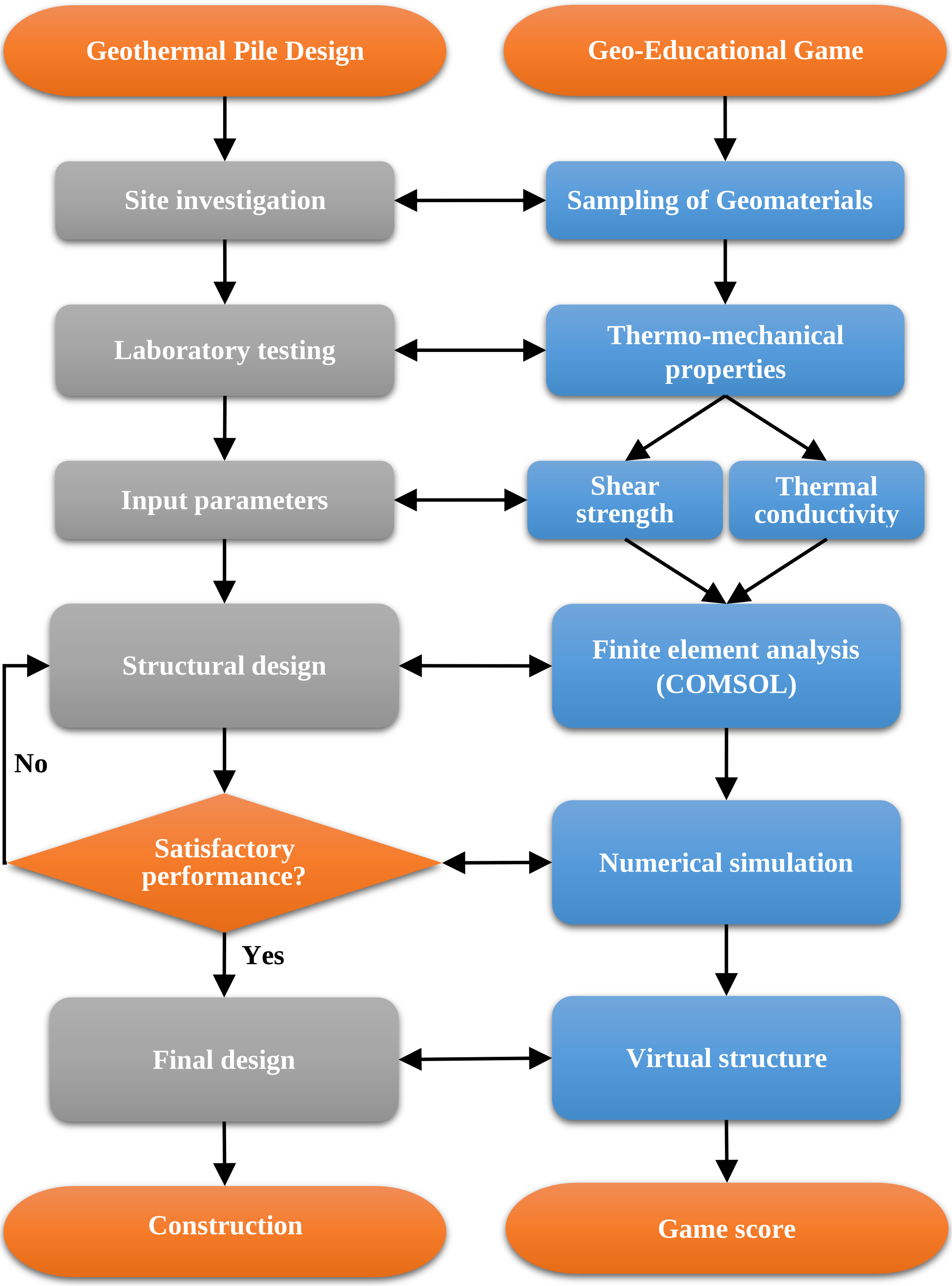


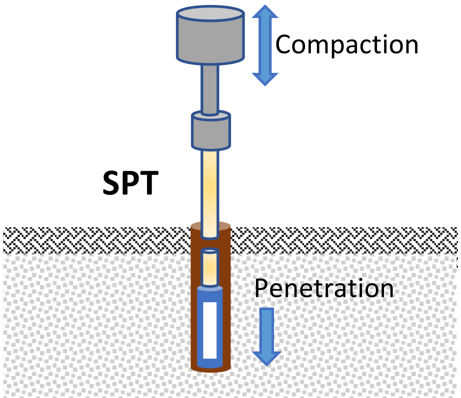
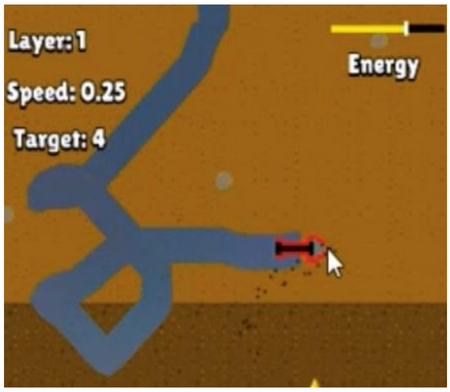
Fig. 1 A scheme of integrated geotechnical education module for a geothermal pile design.

Development of Geo-educational Game:

We embed the Wallas' four-stage model of the creative thinking process in game development [5]. Essentially, the creative thinking process requires four steps: preparation, incubation, illumination, and verification [5]. As for every creative project accomplished in the society, these four stages are necessary: 1) preparation – gathering sufficient information needed for the project; 2) incubation – undergoing unconscious mental exploration for the solution; 3) illumination – generating the creative idea in the "ah ha" moment by means of trial-and-error method; and 4) verification - implementing the idea with in-depth analyses. The philosophy of the educational game is built on this model, in line with the scientific geotechnical design procedure [2], as shown in **Fig. 1**. The scheme of the game-based learning paradigm is developed based on the technique of mixed reality. We utilize the virtual reality (VR) to visualize the process of a geothermal pile design in the game accordingly [3]. In practice, a geotechnical project normally needs four steps: site investigation, laboratory testing, structural design, and construction. Correspondingly, the geo-educational game provides a virtual environment for soil sampling, determining thermo-mechanical properties, and structural modelling. It could provide the benefits of saving the spatiotemporal resources, while the actual field investigation and laboratory experiments require a lot of effort in preparation and management. Furthermore, the multiphysics enriched game provides a relaxing environment that is helpful for the incubation of creative ideas (i.e., unconscious mental exploration). Students are also expected to apply the means of trial-and-error method to propose various structural designs, which can be immediately verified in the numerical simulation. This could help to stimulate engineering creativity. Overall, the geo-educational game leads geotechnical students towards the mindset of systematical thinking [6].

The educational game leads geotechnical students to complete a project of a geothermal pile foundation toward sustainable development. The components in the project are idealized as several mini-games, as indicated in **Fig. 2**. The field investigation is normally conducted by the standard penetration test (SPT) to obtain the soil stratification information. The geo-educational game visualizes the SPT as a digging game, in which the players can feel more resistance to dig deeper. This is consistent with the physical fact that the penetration resistance increases with the depth [7]. The laboratory tests (e.g., direct shear test and thermal conductivity measurement) are conducted in the game via the VR. The three-dimensional visualization of experimental procedures enables students to observe the critical details in the testing. It should be noted that the proposed educational game is considered as a supplementary tool rather than an alternative method of training the laboratory testing skills of students. This educational game makes the experimental procedure clear and encourages students to perform laboratory tests correctly. In the case of structural design, the traditional method relies on the "tedious" equations and design codes, while the educational game reveals the underlying physics of the structure and visualizes the force chain, heat & moisture flux, and deformation. This provides instant feedback to players and allows students for the trial-and-error toward a satisfactory geothermal pile foundation. Ultimately, the designed geothermal pile foundation can be constructed in the virtual world, which helps students to evaluate the performance (in terms of the bearing capacity and heat exchange efficiency) of the structure. It can make students have a sense of fulfillment for their design and stimulates their engineering creativity.

We believe that the proposed scheme of an integrated geotechnical education module can improve the learning experience for students. The mixed reality of the game could stimulate engineering creativity by exposing students to the creative thinking process (i.e., preparation, incubation, illumination, and verification) in a virtual environment.

<table>
<tr><th>Geotechnical</th><th>Practical Reality</th><th>Virtual Reality</th></tr>
<tr><td>Field investigation</td><td>
</td><td>
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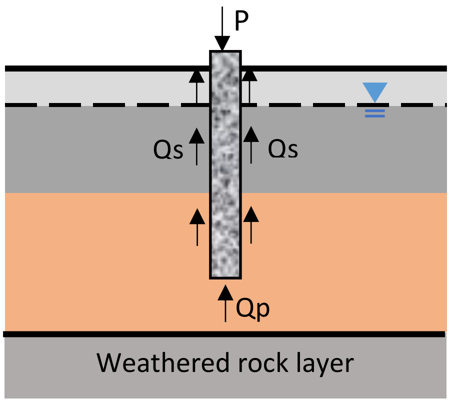
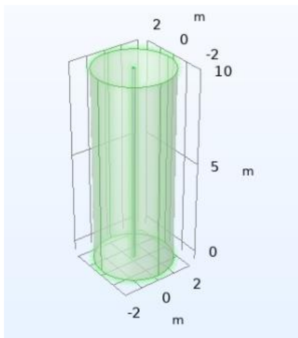
<tr><td>Structural design</td><td>
</td><td>
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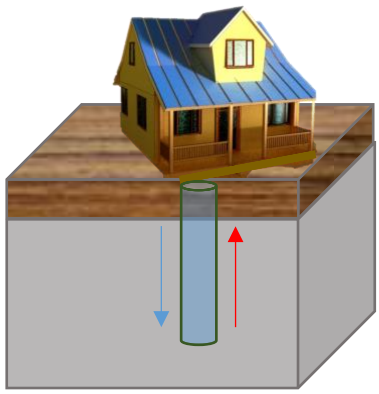
Construction		

Fig. 2 Mixed reality of geotechnical education.

Engaging features of the game:

Apart from achieving educational purposes, the development of the game attempts to keep players engaged and joyful. We involve multiple elements in the educational game (**Fig. 3**). There are different characters (i.e., avatar), tools, and situations for developing the game story. Players are free to choose their own avatar in a preferred style (e.g., gender, color of the clothes, and posture). Various tools are provided in the game, including hand rakes, molds, wash bottles, pickaxes, sensors, direct shear devices, etc. These tools are provided to conduct different activities such as soil sampling and thermal conductivity measurement (refer to **Fig. 1**). Different circumstances are created in the virtual world, including the construction field, geotechnical laboratory, and engineer office. We use the VR technology to simulate the actual environment and show real-world problems [8]. The game also provides detailed instruction to guide players to complete the educational tasks. The game score is used to evaluate the participation and performance of students in the gameplay. These enriched elements in the game could provide students with a competitive and fun experience.

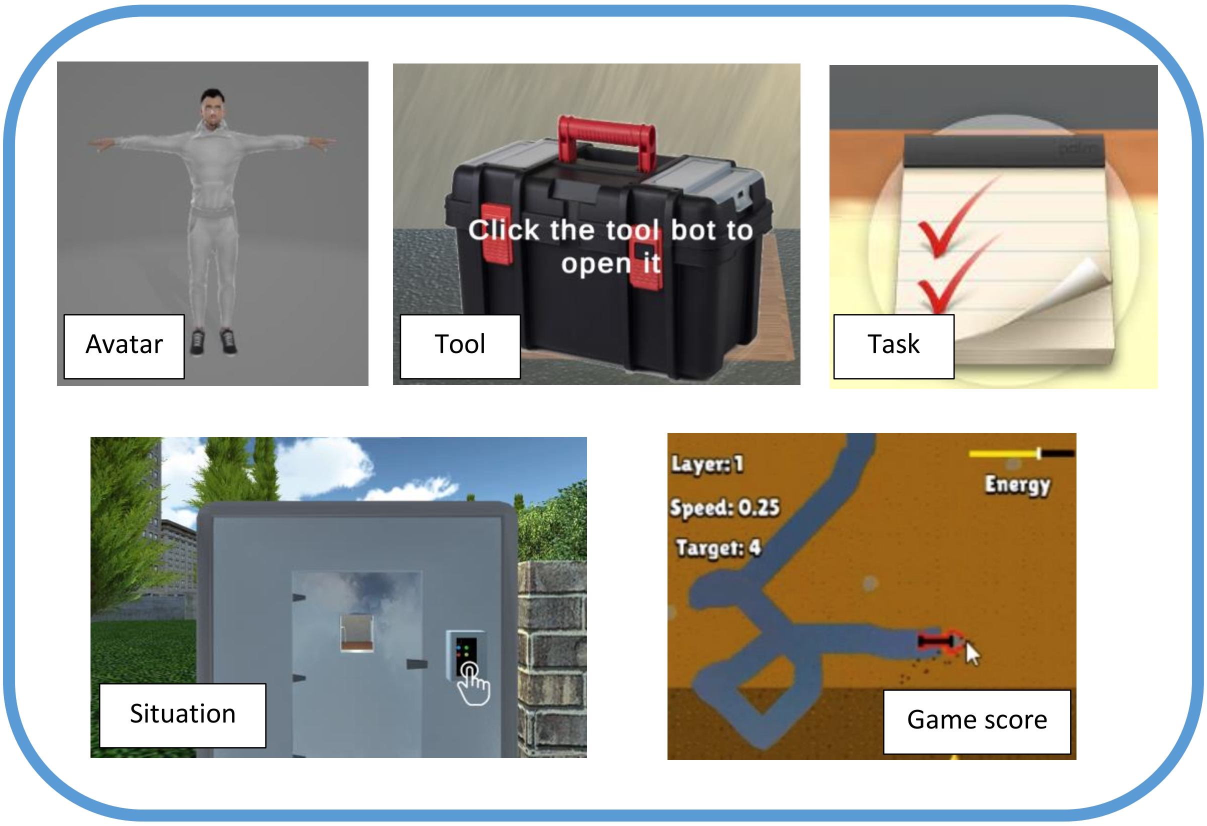


Fig. 3 Enriched elements in the story-based and task-driven educational game.

Educational outcomes behind the game playing:

The discipline of geotechnical engineering generally comes from physics-based (i.e., theory) and data-driven (i.e., experiment) studies. Traditional geotechnical practices involve multiphysical problems, including structural mechanics, flow conduction phenomena, granular behaviors, and the associated solid-fluid couplings [9]. In the current study, we utilize two basic theories for understanding the thermo-mechanical behaviors of the geothermal pile, as shown in **Fig. 4**. The geo-educational game is designed to teach students with the Mohr-Coulomb failure criteria and Fourier's law to understand the mechanical behavior and heat conduction phenomena, respectively [10]. In the virtual environment, the direct shear test is conducted to obtain the shearing resistance of the soil under various vertical pressures and the measurement of thermal conductivity is performed at different locations of the soil sample. The direct shear test is performed to obtain the strength characteristics (i.e., friction angle and cohesion) of the Mohr-Coulomb failure criteria. Students are expected to comprehend the stress-dilatancy relationship and apply the strength characteristics to estimate the bearing capacity of the geothermal pile [11]. The thermal conductivity is used to interpret the heat transfer (in a steady or transient state) and the associated geothermal energy extraction [10].

We anticipate that the educational game exhibits the role of fundamental soil mechanics on different scales. From small-scale laboratory tests to macroscopic behaviors of a geothermal pile foundation, mechanical and thermal responses are in line with the Mohr-

Coulomb failure criteria and Fourier's law. This demonstrates that students are capable of and responsible for engineering the geotechnical infrastructures to meet the needs of the society.

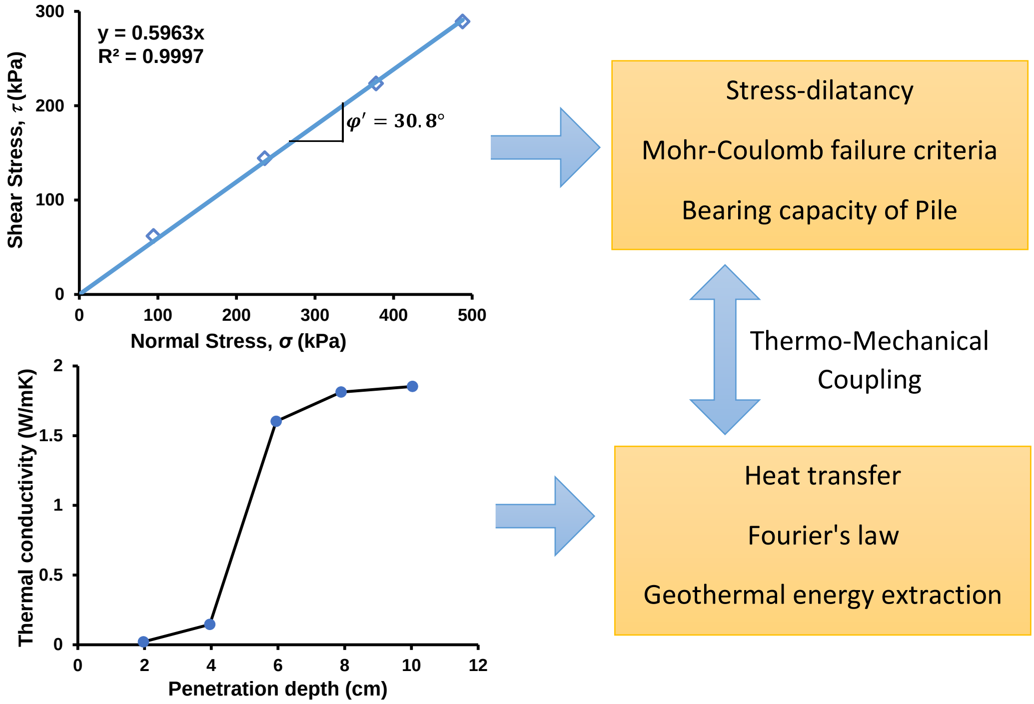


Fig. 4 Laboratory testing of geomaterials: towards thermo-mechanical responses.

The numerical simulation in COMSOL provides the feasibility for students to creatively design the geothermal pile. As shown in **Fig. 5**, there are numerous choices for making a geothermal pile. Players can define any configuration (i.e., geometry of the pile) and boundary condition (i.e., loading conditions, temperature gradient, porewater pressure) of the geothermal pile [10]. Multiphysics (e.g., heat transfer, water movement, strain-stress relationship) can be applied to interpret the thermo-mechanical behaviors on finite elements. Once the design of the geothermal pile is completed, the data visualization (e.g., heat exchange efficiency) can be achieved via various methods such as figures, tables, and animations. Such feasibility can stimulate the engineering creativity of geotechnical students. The optimized solution might be explored through this numerical technique.

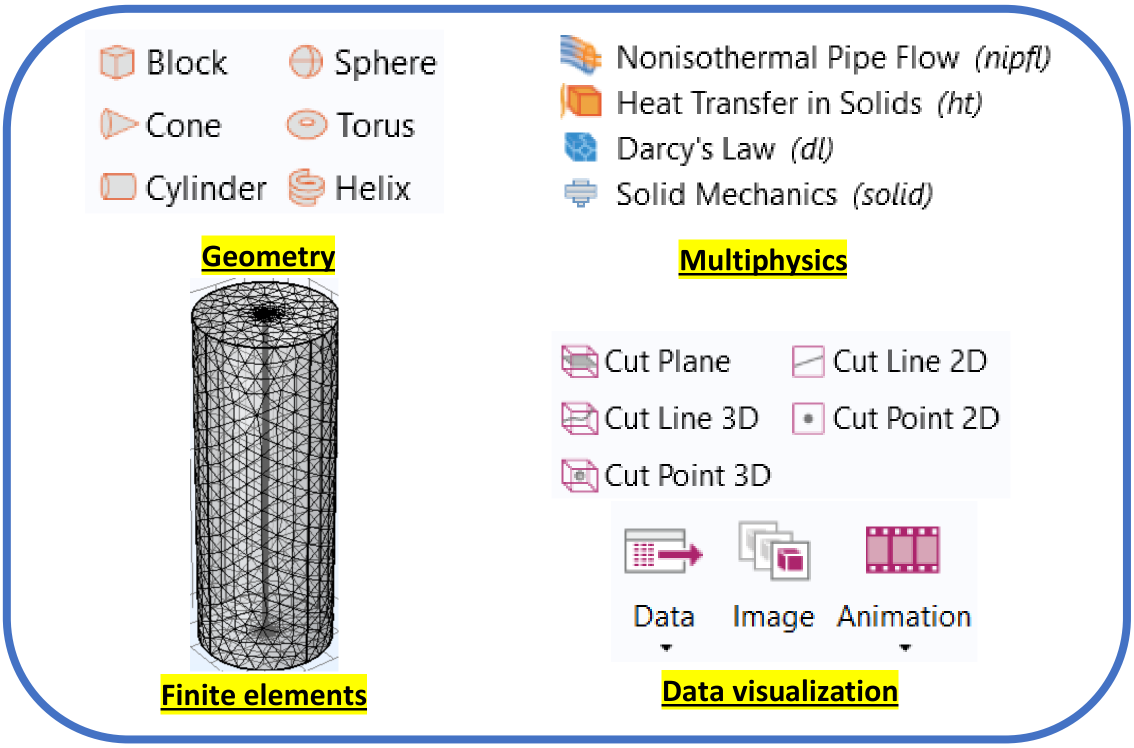


Fig. 5 Numerical modelling of geothermal pile.

Conclusion:

The educational game using multiphysics enriched mixed reality is proposed to support the undergraduate geotechnical engineering education. Based on the philosophy of the KPA theory and the Wallas' four-stage model, we develop the game to stimulate the engineering creativity of students and improve the learning experience of geotechnical engineering education. The story-based and task-driven gameplay engages students with fundamental geotechnical concepts in a pleasant way. This newly developed educational game can help the lecture instructors to expose students to a systematic geotechnical design framework, including laboratory testing, field investigation, structural design and analysis.

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