# A NEW FRAMEWORK TO DESIGN AND GENERATE VIRTUAL LABORATORIES FOR CIVIL ENGINEERING

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# A NEW FRAMEWORK TO DESIGN AND GENERATE VIRTUAL LABORATORIES FOR CIVIL ENGINEERING

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**I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.**

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# ABSTRACT

## A NEW FRAMEWORK TO DESIGN AND GENERATE VIRTUAL LABORATORIES FOR CIVIL ENGINEERING

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For years, practicing the theoretical parts in a laboratory has played a substantial role in the engineering education system. Building a laboratory for most engineering departments has a cost that many universities might find difficult to cover. Unfortunately, even with a laboratory built, the global pandemic does not allow students to use laboratories like they used to. In such a context, creating virtual laboratories can become a solution. This study developed a framework that allows developers and designers to create virtual laboratory experiments without any additional programming due to its modularity. This modularity stands as a strength since it is open for adding and subtracting new modules or hardcoded function blocks. The main focus of this framework was to virtually create the laboratories for the Soil Mechanics course of the Department of Civil Engineering. However, thanks to its modularity, the framework can create virtual laboratories for different classes and departments of engineering. Within the framework, a virtual laboratory for the soil mechanics course of civil engineering was developed, and the system passed through a two-phase design period, based on the usability tests from the users.

Keywords: Virtual Laboratory, Simulation, Game Generation, Framework, Usability.

# ÖZ

## İNŞAAT MÜHENDİSLİĞİ İÇİN SANAL LABORATUVAR TASARIMI VE ÜRETİMİ İÇİN YENİ BİR ÇERÇEVE

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Mühendislik eğitim sisteminde, teorik kısımların laboratuvar ortamında uygulanması yıllar boyunca önemli bir rol oynamaktadır. Mühendislik bölümlerinin çoğu için bir laboratuvar kurmak, birçok üniversitenin bütçesi tarafından karşılanması zor olabilecek bir maliyete sahiptir. Bir laboratuvar inşa edilmiş olsa bile, küresel salgın öğrencilerin laboratuvarları eskisi gibi kullanmasına izin vermemektedir. Bu durumda, sanal laboratuvarlar bir çözüm olarak sunulabilmektedir. Bu çalışmada, modülerliği nedeniyle geliştiricilerin ve tasarımcıların herhangi bir ek kodlama yapmadan, sanal laboratuvar deneyleri oluşturmalarına olanak tanıyan bir çerçeve geliştirilmiştir. Bu modüler yapı, yeni modüller veya modül oluşturmayan kod blokları eklemeye ve çıkarmaya açık olduğu için, çerçevenin gücü olarak durmaktadır. Bu çerçevenin ana odak noktası, İnşaat Mühendisliğinin Zemin Mekaniği dersinin laboratuvarlarını sanal olarak oluşturmaktır, ancak modülerlik sayesinde çerçeve, farklı mühendislik dersleri ve bölümleri için sanal laboratuvarlar oluşturabilmektedir. Bu çerçevede, inşaat mühendisliği zemin mekaniği dersi için sanal bir laboratuvar geliştirilip ve test edilmiştir.

Anahtar Sözcükler: Sanal Laboratuvar, Simülasyon, Oyun Üretimi, Çerçeve, Kullanılabilirlik.

To My Family and Friends

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| | |
|---|---|
| **CE** | Civil Engineering |
| **CS-R** | Computer Science Related |
| **TAM** | Technology Acceptance Model |
| **GMP** | Gamer Motivation Profile |
| **SUS** | System Usability Scale |
| **CPT** | Core Penetration Test |
| **ESP** | Effective Stress Program |
| **UI** | User Interface |
| **Cu** | Coefficient of Uniformity |
| **URP** | Universal Render Pipeline |
| **CGS** | Curved Grading Scale |

# CHAPTER 1

# INTRODUCTION

## 1.1 Definition of the Research Problem

In recent years, with the COVID-19 pandemic, the medium of the educational facilities needed an adaptation to this new situation. It can be seen that this drastic event caused an increase in the demand for virtual education. Learning through the virtual laboratory and simulation method has been the subject of various studies before. As an alternative to traditional education, where the laboratories and experiments are conducted face-to-face, virtual laboratories are a different way of providing the continuity of educational actions, especially in extreme and unexpected events such as a pandemic.

It is known that the education and experience gained from laboratory courses in the engineering field are integral parts and cannot be ignored. When physical learning is not feasible as it has been during pandemics, where this demand for the laboratory experience and learning cannot be addressed, online laboratory practice provides help to overcome this lack in the reinforcement of the material that is learned in the classes. In such a context, virtual laboratories have shown to be beneficial, allowing students to get consistent, low-cost, and enjoyable training.

The main research question of this study is "How well can generated virtual laboratories be integrated into the current education system, especially in civil engineering, as supplementary material?."

## 1.2 Aim of The Research

This thesis started during the Covid-19 pandemic with the need for quality during the online education period. While the initial idea was to create supplementary material for distant education, it was later realized that many universities could not provide a quality laboratory for students to test and explore due to the high cost of building such laboratories.

The main objectives of this thesis are listed as:

- To provide a generic framework that can be used by developers, designers, and scholars.

- To provide a virtual laboratory that is not a replacement for real-life laboratories but a supplementary method for students to practice and experiment on.
- To test the usability of generated content within the framework.

### 1.3 Research Method

This thesis research aims to establish a generic modular virtual laboratory framework that game designers and developers may utilize to build lab experiments with minimal coding. The modular structure of the framework makes it simple for programmers to implement additional capabilities. Twenty-four people (12 from the Civil Engineering Department and 12 with backgrounds in Computer Science-related degrees) worked within the framework to develop and test a virtual lab for the Soil Mechanics course. The study consists of two phases: in the first phase, participants test out the game, while in the second, they test out a new version that incorporates their feedback. The resulting game's usability and acceptability are measured with standard questionnaires like the Technology Acceptance Model, the System Usability Scale, and the Presence Questionnaire Item.

### 1.4 The Contribution and the Novelties

This study positions itself in the field of virtual laboratory generation. It distinguishes itself from the other studies in the literature by creating scenario-based game generation frameworks for the desired departments, specifically in the soil mechanics laboratory of the civil engineering department. In addition to this, the framework allows its users to not only generate user-interacted experiments (by themselves) but also grants the ability to create watch-only experiment simulations. This modular framework is highly compatible with the quickly changing situations in the experiment simulation due to its scenario structure. Even though there are other virtual laboratories [43-48] available in the literature, the study of this thesis covers the gap in the need for an immediate change of the variables, fast-paced development of the virtual laboratories, and experimentation with different possible scenarios. Furthermore, when the system's modularity is not responding to the users' needs, the framework is available for developers to insert new needed modules.

An article from this study, titled "A Modular Game Development Framework with a Focus on Generating Serious Games for Virtual Laboratory Courses: Soil Mechanics Course as a Use-Case," has recently been submitted to a journal, and it is currently under review.

## 1.5 The Outline of the Thesis

The rest of the thesis is outlined as follows: Chapter 2 presents a literature survey of serious games, serious games in education, and civil engineering. In the following section, Chapter 3, the material and methods used in the development of this framework are introduced. In Chapter 4, evaluation methods and criteria are explained. Chapter 5 discusses the questionnaire results of the System Usability Scale, Technology Acceptance Model, Presence, and participant comments. Chapter 6 is the discussion, Chapter 7 is the conclusion of the study, and potential future work is presented.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Serious Games

Education takes precedence over amusement in a “serious game”. It employs game design, game components, and game graphics to instruct or educate students by providing them with opportunities to apply their knowledge. The 3D Wild Land Fire Simulation [35] enables firefighters to gain experience in various decision-making situations, including those with stringent time constraints. It enables users to study and train in a controlled and secure environment by imitating various situations [22]. Illness and natural disasters are two instances of these conditions. Conditions favorable to instructional efficacy.

In the healthcare industry, management and training simulation board games are utilized. Jarvis and de Freitas [25] discovered that persons who practiced the triage method using serious games fared better. Smith et al. [20] provide yet another illustration of decision-making using serious games. They designed a matrix game to employ critical thinking around infectious disease preparedness and response. According to their findings, such an application can simulate decision-making in a real-world crisis and evaluate ideas and cooperation in relation to global health issues.

Several studies made in Middle East Technical Universities have been the basis for this thesis. The first one was Sürer et al. [47], where a scenario-based serious game generator was developed. The goal of that research was to create a serious game generator with a variety of settings, and two of those settings are Hospital and Biogarden. A comparison has been made between the framework and two different serious games created based on the findings of the study’s scenarios.

The second one was by Yücel et al. [56], where a generic framework for crowd simulation was developed. That study focused on crowd simulation-base puzzles using the firefly algorithm, particle swarm optimization, and artificial bee colony algorithm. The authors suggested that those puzzles can be used in teaching and testing crowd simulation algorithms. In this thesis, a virtual laboratory generation framework is developed, and generated games are tested.

## 2.2 Serious Games in Education

Hamari et al. [24] studied the effect of games on the learning experience. They developed two different games which are Quantum Spectre and Spumone. In that study, they tested 173 players, 134 tested Quantum Spectre, and 40 tested Spumone with just one person in both tests. During those, a positive effect on being engaged and immersed was observed. As a result, the authors suggested that games' difficulty levels should be able to keep up with players learning process.

It was stated by Morsi et al. [36] that video games can be a powerful learning tool with the potential to reach many people with a selective learning style. The paper focused on the development of a 3D educational game on the platform of PC and Mac. The games' main focus is teaching core concepts in Electrical Engineering, Computer Engineering, and Digital Logic Design. The authors developed the 3D adventure game where players are in an outer space engineering research facility to teach the topics such as number systems, boolean algebra, and combinational and logic design. The game was developed and built in Unity 3D.

Roozeboom et al. [7] made a study that included three empirical studies comparing serious games to a traditional classroom education regarding learning results. All three studies that assessed the same learning elements such as control, challenge, feedback, engagement, and social interaction. They used self-assessments and self-reports to evaluate the learning outcomes. According to their three research, students who played serious games had higher learning scores. The results indicate that serious games are more effective than traditional classroom teaching in terms of self-reported learning outcomes. They reported that there were no effects of severe gaming on knowledge tests were seen.

Westera et al.'s [50] work presents a computational model for studying, learning, and playing serious games. They proposed a formal model to investigate serious games players would play in different settings. They proposed a theory called cognitive flow theory which quantifies player action and motivation. They developed 7 different simulations with over 100,000 iterations, showing their project's potential as a serious gaming research tool. The authors claimed that their model helps academics to study quantitative relationships between game factors, understand how individuals learn from games, and improve serious game design.

Students' learning results and Serious Educational Game experiences were explored in Cheng et al.'s [13] study. They collected data using mixed-method research, resulting that they had both quantitative and qualitative data. A paper-and-pencil survey, interviews, and video recordings were conducted with 98 kids in grades six through eight. They claimed that after playing the game, students learned more about neurobiology and became more opposed to methamphetamine use. Furthermore, participants used cognitive and metacognitive tactics to tailor the Serious Educational Game to their learning styles and improve their cognitive abilities.

Van der Wal et al. [49] made a study with the first goal of using computer simulation models to solve complicated natural resource management problems, with social learning as a secondary goal. Participants obtained feedback from an Integrated Assessment Meta Model through a serious water management game in their study. Their study looks into social learning and the role of role models. Ten of the twelve game sessions showed evidence of social learning. Social learning was driven by the team's reflection on their perspective, not model input. They claimed that the employment of a model in a serious-game situation could increase social learning, especially when combined with team reflection.

### 2.2.1 Serious Games in Civil Engineering Education

In general, too many virtual laboratories were observed in the 2000s in the field of civil engineering, especially in geotechnics. Thus, it is evident that the virtual laboratory concept predates the COVID-19 epidemic and is not new. In this section, virtual laboratories in engineering education than in civil engineering will be discussed, followed by geotechnical research. The majority of research tries to expand the knowledge and experience of pupils. Nevertheless, some have created virtual worlds that students and the commercial world can utilize. Several studies are included below.

Wolf [52] stated that laboratory experiments had a significant impact on student education but expressed dissatisfaction with the expensive cost of laboratory experiments. As a result, Wolf [52] said that virtual laboratories are beneficial in terms of cost. Wolf [52] also researched how student comprehension develops with the virtual laboratory in various fields, including geotechnical engineering.

Deshpande and Huang [18] published a study titled "Simulation Games in Engineering Education." They argued that simulation games have no boundaries, distinguishing them from traditional education. They claimed that in a virtual space, pupils assume responsibility and make their own decisions, whether they are correct or incorrect. As a result, even in a virtual world, people can learn what is right and wrong through experience. They claimed that simulation games had various advantages. For example, the competitive setting of games boosts students' motivation; therefore, games motivate students to investigate and learn more as a result of this aspect. Another benefit they highlighted is that games make it easy for students to access their course or laboratory because they can play the game and study anywhere and at any time. Because all background calculations are done by machine, the significant advantage they said is that students construct diverse tactics by attempting different alternatives and focusing on the logic of the subject rather than the result.

Yarbrough and Gilbert 54 suggested that students could acquire only the probability and statistics theories necessary to finish their assignments and exam in the civil engineering probability and statistics sector. However, the theory cannot solve an actual technical problem. In other words, despite their academic accomplishment, pupils were unable to apply their knowledge to the actual issue. Using a virtual laboratory, they aimed to bridge the knowledge gap between the classroom and real-world scenarios and provide students with a new viewpoint, for instance, that a high grade should not be their primary focus

Hall et al. [23] designed a course game for Statics and Material Mechanics. They concentrated on necessary computations for these classes. Calculations involve locating the centroid, the first instant of area, and Mohr’s circle. They said that their game features a competitive and entertaining atmosphere. Their game aims to familiarize students with these essential computations; hence, its content is repeated. The Centroid game has two sections. The first objective is to locate the centroid of the shape generated by the union of the rectangles, while the second objective is to locate the centroid of the composite bodies. The leveling system was utilized for the centroid game. It contains six distinct levels. In the first level, students must determine whether or not the centroid is in the correct location. After the first level, a calculating table is displayed in the game. The second level requires players to identify incorrect information. After the second level, students must fill in the table with the correct response. In the final level, students must compute the centroid. Students must identify the right area for the first instant of the area game to calculate the first moment of the area. In the final step of Mohr’s circle, players must draw Mohr’s circle. The game explains why their solution is incorrect when their drawing is incorrect.

Balali et al. [8] track and illustrate cost estimation through virtual reality combined with Building Information Modeling. They noted that the standard cost estimation methods involve pen and paper calculations. In the building sector, Building Information Modeling is a growing trend. Building Information Modelling decreases the time and money required for cost assessment. In addition, they claimed that any design changes made by uninformed stakeholders have a negative impact on the budget and schedule of the project. In addition, they provided an example of how the owners’ primary focus is typically interior design, whereas the owners’ primary priority should be material selection. In addition, owners typically alter the design until it meets their expectations. A lack of communication and technology is responsible for all of these issues. Using virtual reality, stakeholders may view the project, alter the design, and observe the impact on budget and schedule.

Awwad et al. [5] created a virtual laboratory for construction bidding using agent-based modeling since the construction bidding process is extremely risky. There are multiple ways to win the project. To create this virtual laboratory, it is necessary to comprehend the dynamics of construction bidding. They mentioned that their research employs both analytical and empirical methodologies to analyze the building bidding process. They intend to develop an agent-based model to examine the construction bidding’s complexity, dangers, and decision-making.

Sim et al. [17] remarked that dynamic testing is challenging to demonstrate and repeat due to the high expense. Sim et al. [17] created a virtual laboratory for linear and non-linear dynamic analysis in structural dynamics using the Java computer language.

Gao et al. [19] argued that earthquake engineering fundamentals could not be taught effectively in the classroom. Important earthquake engineering ideas must be taught since students are future engineers who must design and construct earthquake-resistant structures to prevent the massive loss of life. Gao et al. [19] asserted that laboratory experience enhances subject comprehension, so they created a virtual laboratory in earthquake engineering to illustrate the non-linear dynamic analysis.

Bennett et al. [10] state that laboratory instruction cannot be fully grasped through small sample size laboratory examinations, yet accurate field tests are costly for students. In addition, Bennett et al. [10] claim that children can experience harsh situations safely through games. Consequently, a virtual laboratory is the optimal setting for education. They created a game known as GeoExplorer. They are the source of two games. Levee Patroller is one of them; it focuses on handling failures such as flooding. CPT Operator focuses on the cone penetration test and related methods. Students must create levees to prevent flooding because the objective of the GeoExplorer game is to examine the given site for slope stability and flood danger.

Bennett et al. [10] stated that their objective is to provide field experience and practical training. GeoExplorer is a game designed to bridge the gap between classroom instruction and outdoor experience. The game focuses on the regularly used geotechnical in-situ test, the cone penetration test (CPT). Before students play the game, they receive a lesson on the cone penetration test (CPT). The game features two unique scenarios. They must conduct CPT based on the circumstances. For instance, they must determine at what depth they ended the test. In addition, Bennett et al. [10] surveyed the difference in knowledge between students playing the game. There is a survey administered before the game, and there are questions that assess whether or not students have learned from the game; these questions are comparable to the survey questions administered before the game. After the students completed the game, a second survey was administered to assess its usability and general satisfaction.

According to Le et al. [28], the construction business has a high accident rate due to the nature of the labor performed. In addition, they claimed that instruction in the field and the classroom is insufficient for understanding and applying safety regulations and does not raise awareness. Therefore, Le et al. [2I3] devised a collaborative virtual reality game to educate construction workers on basic safety procedures. The game's scenarios are based on actual incidents; thus, they are realistic.

Oliver and Oliphant [38] discovered that students struggle with the vital idea of soil mechanics, the computation of effective stress. In addition, they discovered that the conventional instruction technique is insufficient for teaching this topic. Consequently, they developed ESP (Effective Stress Program), a computer-assisted learning application. They thought computer-based learning tools should supplement rather than replace traditional educational techniques. Their computer-assisted learning software includes subject theory, example problems, and tests. After pupils complete a test, the application provides feedback on their incorrect responses.

Alani and Barnes [1] complained that students lack confidence because they view the laboratory technique as a formula. In addition, students are unaware of the experiment prior to the laboratory session and do not have the opportunity to repeat the experiment afterward. Therefore, a computer-assisted virtual Soil Mechanics Laboratory was created. The virtual laboratory consists of the Soil Mechanics Laboratory photographs, technical data, and questions. This is a video-based virtual lab supplemented by simultaneous graphics and animation.

Amaratunga and Sudarshan [2] created a virtual laboratory to monitor an existing infrastructure system for wind loads, specifically a 31-meter flagpole. They created a web interface to monitor the system from any Internet-connected location. Their primary objective is to educate students about new technologies and sensors utilized in infrastructure projects.

Wyatt et al. [53] argue that laboratory education is insufficient due to high laboratory costs and low laboratory knowledge among undergraduate students. Due to these constraints, the fundamental experiment is demonstrated. They discovered a solution resembling a virtual laboratory, creating a virtual reality laboratory experiment. The game was designed for triaxial strength tests. Then, any tests may be conducted, and students may conduct the experiment under various situations. Students can, for instance, alter drainage parameters for the triaxial experiment and observe the effect on shear stress in the game. The game was created by Wyatt et al. [53] using the programming language C and the OpenGL graphical package.

Garca-Vela et al. [11] state that after the government halted face-to-face education in their country, which is Ecuador, due to the COVID-19 pandemic. They shifted to online education and created virtual laboratories for Civil, Geology, Mining, and Petroleum Engineering fields because laboratory and field trips are essential for these fields. They utilized a block-based programming language known as CoSpaces Edu.

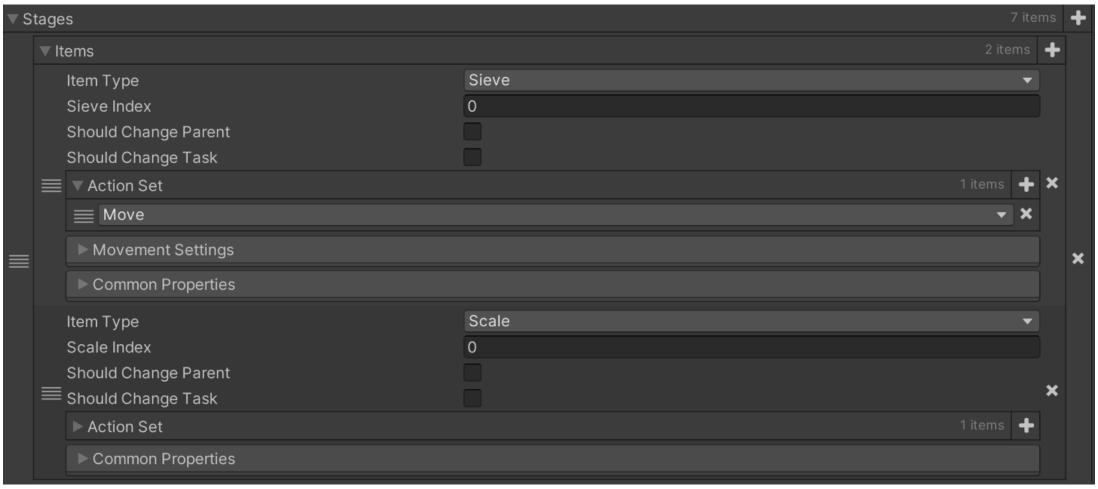
Kim and Rix [27] revealed that standard learning approaches are insufficient to teach students how to apply theoretical knowledge to solve practical engineering problems. Kim and Rix [27] concentrated on on-site exploration. According to Kim and Rix [27], students do not have the opportunity to conduct a comprehensive site investigation since teachers are required to present pre-planned site investigation and field test reports from some organizations due to time and expense constraints. Then, Kim and Rix [27] created a simulation of a site examination. Therefore, students can independently organize and perform site investigations in a risk-free manner. Their simulated site investigation is as follows. Teachers give all site information at specific locations, including soil kinds and thickness, features, groundwater level, and soil parameters. The student then chooses a location at random and plans a site investigation. They must choose the type of soil boring method, the type of in-situ test, the depth of the boring, the depth at which undisturbed samples will be collected, and the type of laboratory test. While students deliberate, the approximate cost of the site inquiry is displayed on the screen. In addition, if students make an irrational option, the simulation will issue a warning and prompt them to make a rational decision. After completing the site investigation, students will design a site model based on the findings of the selected tests. On the screen, students can view the correctness and effectiveness of the site research and site model. According to Arduino et al. [3], when students conduct triaxial experiments, they commit several errors that result in subpar outcomes and material and time loss. In addition, Arduino et al. [3] noted that laboratory sessions instruct students on testing processes but also the behavior of soil under various conditions. As a result, they determined that virtual reality is a suitable method for eliminating these issues. They claimed that students might do triaxial experiments with virtual reality and comprehend soil behavior without damaging material or being misled by a flawed experiment.

# CHAPTER 3

# MATERIAL AND METHODS

## 3.1 Framework

The framework aims to make it simpler for game designers, developers, and academics interested in virtual laboratories to embed a laboratory experiment scenario within a game. Because we needed to create a basic framework in order to achieve this goal, we decided to incorporate modularity into the overall structure. In their research, Sullivan et al. [45] found that modularity has the potential to play an important part in the design and development of software. The fact that the framework is modular provides this study with two important advantages: first, it makes it simpler for developers to add changes in the future. In the event that the laboratory experiment requires important changes, it makes them possible. Along with these patterns, we developed a modular scenario structure in order to enable flexibility in a wide variety of framework areas. For the purpose of developing this modular framework, a scriptable object base class was constructed (Figure 1). Using this scriptable object, a person designing a virtual laboratory game is able to assign tasks to items and adjust task orders by selecting an action from a drop-down menu. This is possible because the scriptable object is implemented with a drop-down menu. The reassignment of tasks and activities is made possible by this scriptable object. It is possible to alter the actions and flow of the game by using the common properties. In the event that it is required, developers can subscribe to an event by either adding methods, writing override methods, or altering the Process Action function located on the Item Behavior class. Because of these considerations, we decided to establish modularity by



Stages 7 items
Items 2 items
Item Type: Sieve
Sieve Index: 0
Should Change Parent ☐
Should Change Task ☐
Action Set 1 items
Move
Movement Settings
Common Properties
Item Type: Scale
Scale Index: 0
Should Change Parent ☐
Should Change Task ☐
Action Set 1 items
Common Properties

Figure 1 Parameter tests that are used for the modularity of the framework.

employing a singleton design pattern and an event listener pattern when developing the framework.

The Scenario Manager class controls the system as a singleton. This singleton contains two actions that can be subscribed to by any class. Item Behavior classes are attached to objects with which the user can interact. Two actions are defined: ActionReadyEvent and NextActionEvent. Item behavior classes subscribe to those actions. These actions both have an item type and index enum. This enum is also present in the scenario scriptable object and identifies the item type. On the other hand, the index is used to differentiate between several elements of the same type; for instance, there are six sieves in the simulation. When an action is executed, the action-ready event is invoked, adjusting objects to the appropriate state. When the user presses the action button, the Scenario Manager determines if the user has pressed the correct button; if this is the case, the next action event is triggered, allowing the appropriate objects to do the required actions. The Scenario Manager class is also in charge of the score. If players press the correct action button, they get 10 points; else, they get minus 3 points. The final score determines the success of the experiment.

### 3.1.1 Design Patterns Used in Development

The singleton design pattern by McDonough [29] and the event listener design pattern by Richards [34] were employed throughout the framework's construction. Both of these patterns are considered to be alternative game design patterns. One of the primary factors that led to the selection of the singleton design pattern was that it paves the way for developers to create controller classes that can be accessed by means of a static variable tied to an instance of the class. Because of this static link with an instance, we were able to give any created item in the game the ability to communicate with the management classes without having to reference those classes within Unity. Because of this, we were able to contain the game generation process within the narrative object successfully. The primary reason the event listener design pattern was chosen is that the simulation's primary structure, much like the primary structure of a virtual laboratory, is step-based, and each item waits for the appropriate circumstance to conduct the desired action. The event listener design pattern makes it possible for the framework to have a modular structure. This is possible since it is possible to construct a new module by simply implementing new conditions. The framework might have been constructed using simply one of these patterns; however, because it is a framework that is open to interpretation by developers who could use it, it was constructed utilizing both of these patterns.

#### 3.1.1.1 Singleton Design Pattern

When an instance is the only one of its kind in the scene and must be reachable by various classes, the singleton design pattern may be used (Figure 2). Establishing a static instance of a class and then accessing the desired class through the use of that

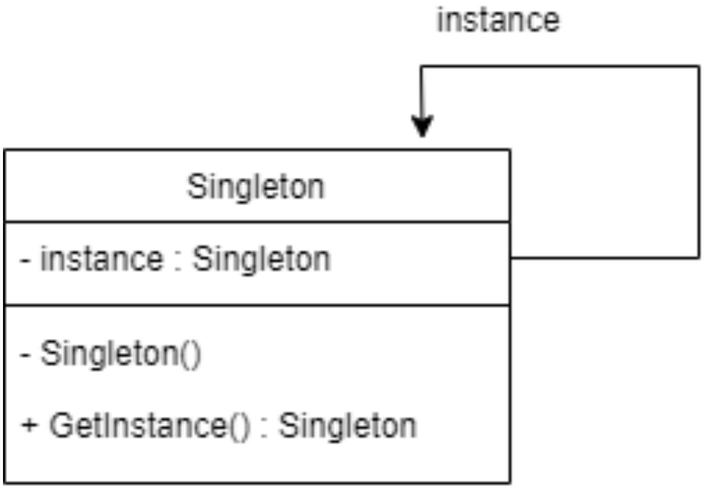


Figure 2 Singleton design pattern.

instance is how it is used. Since the User Interface (UI) manager class and the scenario manager class are constantly communicating with things, our framework implements the singleton design pattern for each class. Because it has the potential to pose development issues in later phases, this design pattern is widely criticized. Nevertheless, these criticisms were taken into account during this study, and the framework was developed with adaptability and readability in mind.

### 3.1.1.2 Event Listener Design Pattern

The Event listener pattern problem addresses the issue of maintaining coherence across an extremely large number of objects that are responsible for monitoring the same actions. In the instance when the subject is altered, this pattern ensures that all of the listeners are informed of the development. Working with event listener design patterns has a number of challenges, the most significant of which is that the structure of the classes must be created in a specific manner. Because of this difficulty, it is imperative to either put into action or alter the structure of the classes. Therefore, event listener design patterns could be used in situations when multiple actions need to be queued and done in a particular order. It is possible that this could be a reasonable answer to the conundrum of how to construct the framework for simulation-style games. Our implementation is used whenever the user performs an action so that it can operate as a simulation of the surrounding environment. This design pattern is utilized whenever necessary by multiple classes contained within the framework. Because it enables developers to utilize it by merely subscribing to an event and does not require any further references from either the data source or the event invoker, this design pattern is frequently quite effective for modularly organized projects such as the proposed framework. This is because it does not require any modular references from either the data source or the event invoker. Within this framework, item behaviors sign up for

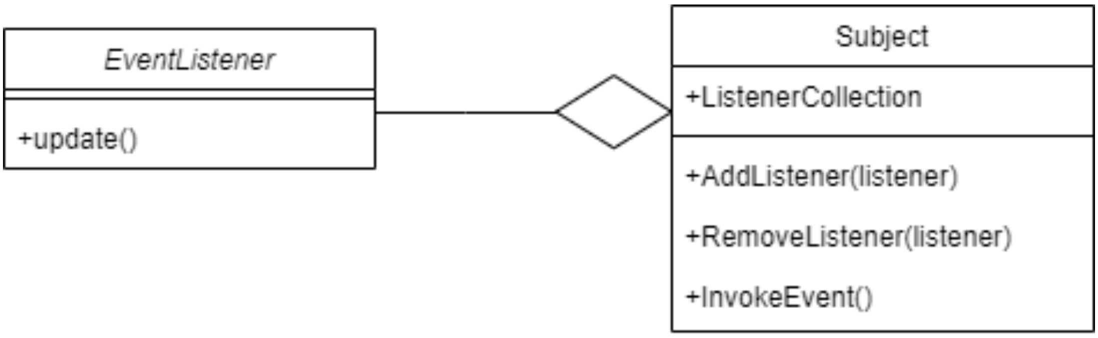


Figure 3 EventListener description.

subscriptions to two distinct events, each of which would convey the necessary scenario data derived from the scenario scriptable object. This pattern is an essential component of this framework since it enables the scenario to be carried out and ensures that the simulation continues uninterrupted (Figure 3).

### 3.1.2 Scenario as a Scriptable Object

In the Unite 2017 presentation, scriptable objects were added to address events and dependencies. When game logic and data are separated, the system becomes more modular. Scriptable objects are Unity Engine built-in classes that share the majority of traits with conventional C# classes. In this study, the scriptable scenario object enables designers and developers to generate the necessary laboratory configuration with a few clicks. The Odin Inspector plugin was used to build a more comprehensible user interface for the scriptable object. With the use of this plugin, the scenario sequence may be altered by simply dragging and dropping this scriptable object, giving designers and developers more control over the laboratory scenario. The framework's scenarios consist of stages, and these stages contain item characteristics. These items convey the data of the next item in use, including its type, index, effect on the UI, the set of actions that the item will perform, the parameters of those actions if the action requires additional knowledge, and some common parameters such as the delay of the action's start after the user triggers it and whether or not the action requires single user input or is automatic. Numerous game events control the scenario, and the scenario manager class performs the laboratory scenario, which is a non-persistent singleton. This manager monitors the game events and adjusts the game's UI and items properly (Figure 4).

The framework's modularity provides designers with modular control over how the game will unfold in the virtual world, allowing them to manage the scenario's effect on student learning progress. Virtual laboratory experiments can be designed with no actions on any steps, simulating the experience of watching a video, or tutorial levels can be designed efficiently with simple actions at the beginning of the scene, allowing players to understand how their actions will affect the virtual world. During the experiment, participants (in this example, students) could be awarded a score based on their performance. This allows the framework to generate tests or quizzes depending

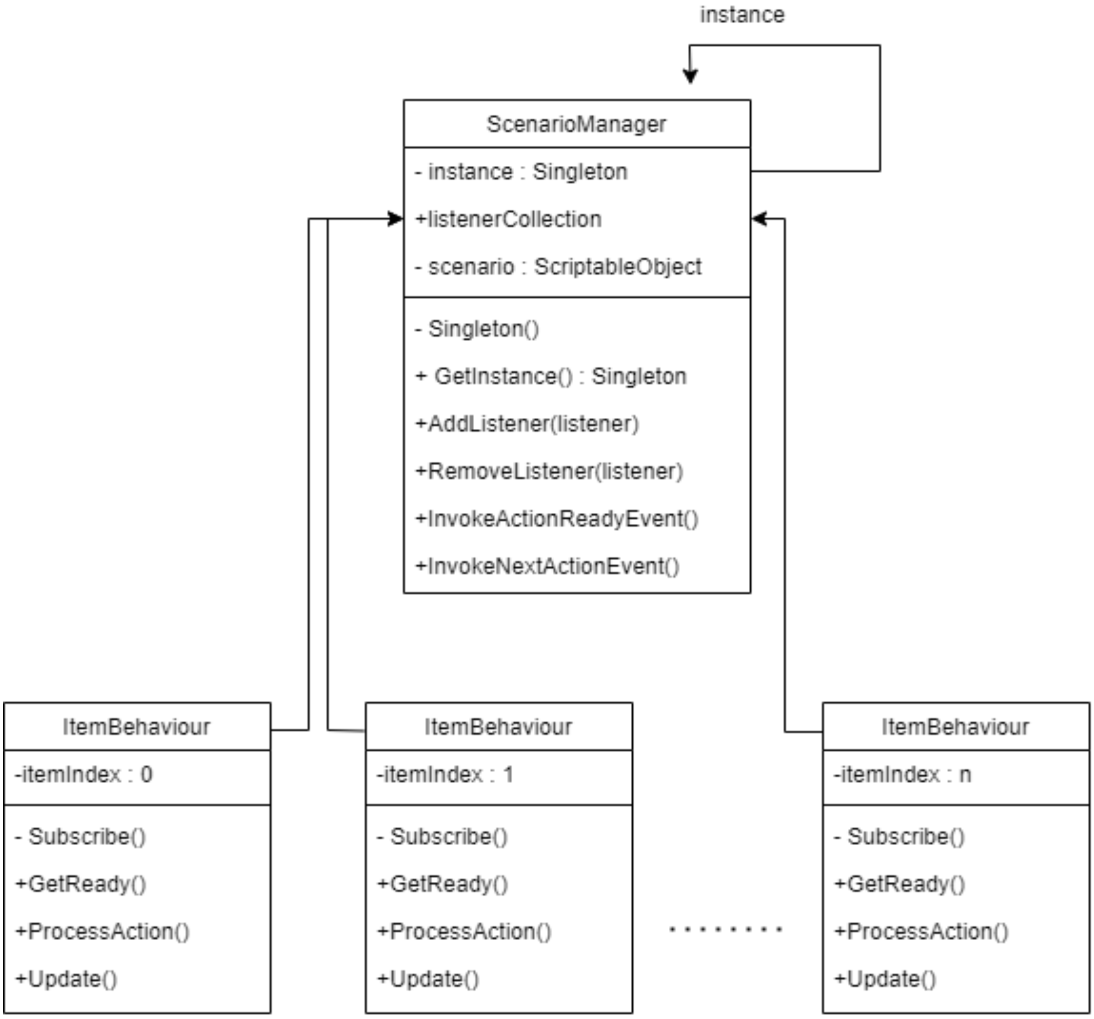


Figure 4 ScenarioManager class used in the game.

on the selected laboratory experiment. User tests are one of the most important game development processes, and the modularity of this framework enables designers to generate many versions of the simulation in a concise amount of time for user tests such as A/B testing and user interviews. During the course of this study, the framework was tested for its ability to generate numerous simulation variants.

### 3.2 Case Study

In order to evaluate the capabilities of the framework, the Middle East Technical University's undergraduate Soil Mechanics course in the Civil Engineering department's sieve analysis experiment was selected as the first virtual laboratory experiment. Because the experiment involves the interaction of items with one another, particle simulations, and other challenging topics for the framework to handle, this laboratory was chosen for the study. The framework was developed using the tools and patterns that were described earlier and was used to implement the game.

### 3.2.1 Course Details

A soil mechanics course for undergraduates served as the foundation for this project. This course covers the fundamental properties of soils, effective stress, seepage, consolidation, soil shear strength, lateral earth pressure, and slope stability. Basic soil characteristics include grain size distribution, soil categorization, soil compaction, and Atterberg limits. Atterberg constraints exist for liquid, plastic, and shrinkage. These are related to the body's water content. Also derived by combining the liquid and plastic limitations is the plasticity limit. Soil compaction is the process of decreasing air volume in order to raise the dry density and attain the ideal soil moisture content. Effective stress is affected by the self-weight of the soil, pore pressure, and the consolidation concept. Effective stress can be divided into three categories for fully saturated soil, which means that all voids in the soil have been filled with water. The self-weight of the soil creates total normal stress, pore water pressure is caused by the water pressure between solid particles, and effective stress is calculated by subtracting total normal stress and pore pressure. Seepage is a phenomenon linked to permeability. According to Craig [16], consolidation is a reduction in the volume of completely saturated soil produced by a change in effective stress. In addition, the course consists of eleven laboratory experiments: sieve analysis, Atterberg limits, specific gravity of solids, hydrometer test, standard proctor compaction test, unconfined compression unconsolidated-undrained triaxial test, direct shear test, laboratory vane test, consolidation, and constant head permeability test.

An experiment including sieve analysis can determine the grain size distribution of coarse-grained soil. The hydrometer experiment examines the fine-grained soil grain size distribution. The Atterberg limits experiment classifies fine-grained soil using plastic and liquid constraints. These three tests are designed to classify soil. Other soil experiments include specific gravity from a solid experiment, optimal water content from a standard proctor compaction experiment, hydraulic conductivity from a constant head permeability test, undrained shear strength of soft clay peak and residual values from a laboratory vane experiment, and unconfined compressive strength from an unconfined compression experiment.

Classification of soil is a crucial concept in this course because once the soil type is recognized, the soil's behavior may be predicted. Therefore, foundations and retaining structures can be developed based on the behavior of the soil. The purpose of the sieve analysis experiment is to categorize coarse-grained soils by their particle size distribution. The ASTM standard [4] defines coarse-grained soil as soil whose particle size is greater than 74 m. The sieve analysis experiment requires an ASTM-compliant sieve set, a digital soil scale, an oven to dry the soil sample, a brush, and a sieve shaker. The protocol for the experiment is as follows. The sample is then weighed, washed, and oven-dried. After the soil sample has been dried, its total dry mass is determined by weighing it. The No. 200 sieve is placed on the pan, followed by the remaining sieves from finest to coarsest. Sieves are then placed on the sieve shaker. The soil is placed within the upper sieve. The top sieve's lid is closed, and the soil is agitated for ten minutes [9]. A bowl is then placed on the digital scale, and the scale is calibrated. The sieves are removed from the top down, and the retained sample is dumped into the basin. If any particles are stuck in the sieve, the sieve is gently brushed, and the particles are then dumped into a bowl. This occurs for every sieve. Following the experiment, the following computations are performed. First, compute the cumulative mass maintained using this formula.

$$\sum_{1}^{i} M_i$$

Then, the cumulative percent retained is calculated using this formula.

$$\frac{\sum_1^i M_i}{Total\ dry\ mass\ of\ the\ soil} * 100$$

Then, cumulative percent passing is calculated using this formula.

$$100 - \frac{\sum_1^i M_i}{Total\ dry\ mass\ of\ the\ soil} * 100$$

The cumulative percent that passes through the No. 200 sieve is used to calculate the fines content. After that, a curve representing the grain size distribution is constructed using the semilogarithmic scale. Particle size is represented along the X-axis, while cumulative % passing is shown along the Y-axis. Then, D10, D30, and D60 are determined, which represent the particle sizes with cumulative passage rates of 10%, 30%, and 60%, respectively. After that, the Cu (Coefficient of uniformity) and Cc (Coefficient of curvature) values are determined by applying the relevant formulas that are listed below.

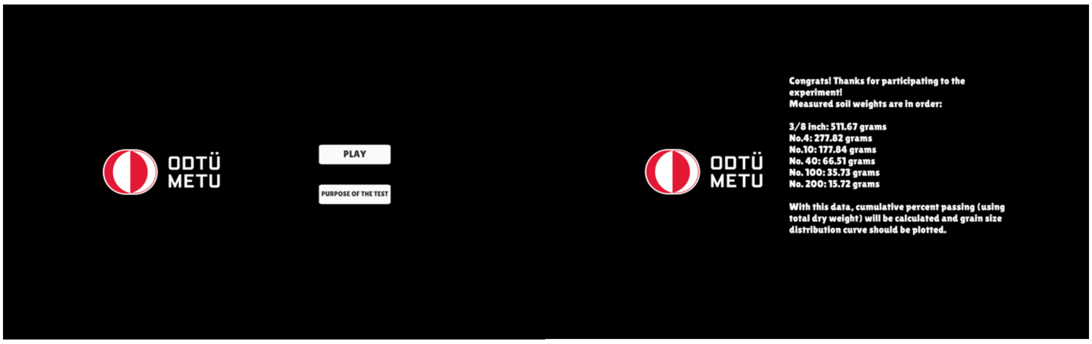
$$C_u = \frac{D_{60}}{D_{10}}$$

$$C_c = \frac{(D_{30})^\wedge 2}{D_{60} * D_{10}}$$

### 3.2.2 Sieve Analysis Game

The game has three components: the main menu, the experiment, and the findings. The main menu (Figure 5a) contains two buttons: the play button, which initiates the experiment, and the purpose button, which displays the test's purpose, which is typically offered to students prior to the laboratory experiment. The experiment contains both user interface and in-game components. It has a score text, a task text, and action panels for the user interface. Elements of the game consist of the 3D models and their movements and interactions. The result (Figure 5b) section is identical to the main menu but contains no buttons; instead, it displays the results of the experiment's measurements. Version 2019.4.18f of Unity 3D was used to construct the game. The game was developed as a WebGL game, and users tested it on their personal computers using different web browsers during separate Zoom sessions.

The transition from version 1 to version 2 consists mainly of performance changes, and the game's tutorials are introduced in response to user input and criticism. During the initial version testing, the WebGL version of the game experienced a number of freezes and ran with diminished quality in a few browsers. To address these concerns, the Universal Render Pipeline (URP) utilized in the original edition has been replaced with the Standard Render Pipeline. In contrast, game assets were duplicated, and textures were eliminated. In addition, the built-in Post Processing tool of the URP and the bloom effect were disabled. Combining dynamic batching and GPU instancing, the number of Draw Calls in version 2 of the game was reduced from 734 to 137. Even though the models in both versions are similar, the first version's 128k vertices were reduced to 35k in the batch. User feedback indicates that these adjustments improved the performance of the game. In addition, shadows were disabled for performance reasons.



Congrats! Thanks for participating to the experiment!
Measured soil weights are in order:

3/8 inch: 511.67 grams
No.4: 277.82 grams
No.10: 177.84 grams
No. 40: 66.51 grams
No. 100: 35.73 grams
No. 200: 15.72 grams

With this data, cumulative percent passing (using total dry weight) will be calculated and grain size distribution curve should be plotted.

Figure 5 Initial and final screens of the game.

The tutorial and score are displayed at the top of the screen. In addition, the info button next to the action button was removed from the game in the second edition and replaced with a single button in the game's primary user interface. A four-step tutorial was used to introduce the action button, where the next assignment is written, the score button, and the info button at the beginning of the game (Figures 6-8).


Next Task: Weigh soils sieve by sieve

Score: 221

Figure 6 A screenshot from the version 1 of the game.


Next Task: Weigh wet soil

Score: 0

By pressing Action button you can interact with the objects in the game.

Figure 7 A screenshot from version 2 of the game, where a tutorial mode is added.

**Next Task: Weigh wet soil**

**Score: 0**

**No.4**

No. 4 sieve has 4.76 mm opening. It separates sand and gravel sizes. Overloading limit of No. 4 sieve is 325 grams.

**No. 200**

No. 200 sieve has 0.074 mm opening. It separates coarse-grained and fine- grained soil. Overloading limit of No. 200 sieve is 20grams.

**Brush**

Should be used when soil is stuck to sieve

**Sieve Shaker**

Sieves need to be shaken 10 minutes according to ASTM 6913.

**Oven**

Dry at 105 degrees overnight (typically 16–24 hours, but depends on the amount of soil and amount of water in it. To make sure that the specimen is dried, check recommended procedure at ASTM ... )

Figure 8 Information screen from the game.

# CHAPTER 4

# EVALUATION

## 4.1 Participant Selection

In order to evaluate the usability of games that were developed, we requested the assistance of volunteers who had previously taken part in the laboratory and had experience either in computer science and game development or in civil engineering. Computer scientists had previous experience in the video games industry, enabling them to evaluate, discuss, and give comments about the generated laboratory. On the other hand, civil engineers had previous experience with the real-world version of the generated laboratory experiment. Because the impacts on learning were not the primary focus of this research, one of the selection criteria consisted of the participants' capacity to use the laboratory experiments that were developed. In total, there were 24 people who took part in this experiment. Twelve of them were students in the civil engineering department, while the other twelve were in computer science-related departments (mainly Multimedia Informatics and Computer Engineering). In total, thirteen of the twenty-four individuals were returning to the experiment after having taken part in it previously in the laboratory. Six of the participants considered themselves to be non-gamers, eight of them described themselves as casual gamers, seven of them as core/mid-core gamers, and three of them as hardcore gamers.

## 4.2 Experiment

Studies were conducted in one-on-one Zoom sessions, and participants used their own personal computers and internet browsers to connect to the game's website, as seen in Figure 9. The experiments were carried out successfully. Before the participants were requested to play the game on their own without any assistance from the observer, they were provided with a brief explanation of the project, along with its objectives and reasons for existing. It was also prohibited for the players to ask about the in-game tasks that were expected of them at any point throughout the game. After each of the participants had successfully completed their tasks, the questionnaires for which they were to provide responses were delivered to them.

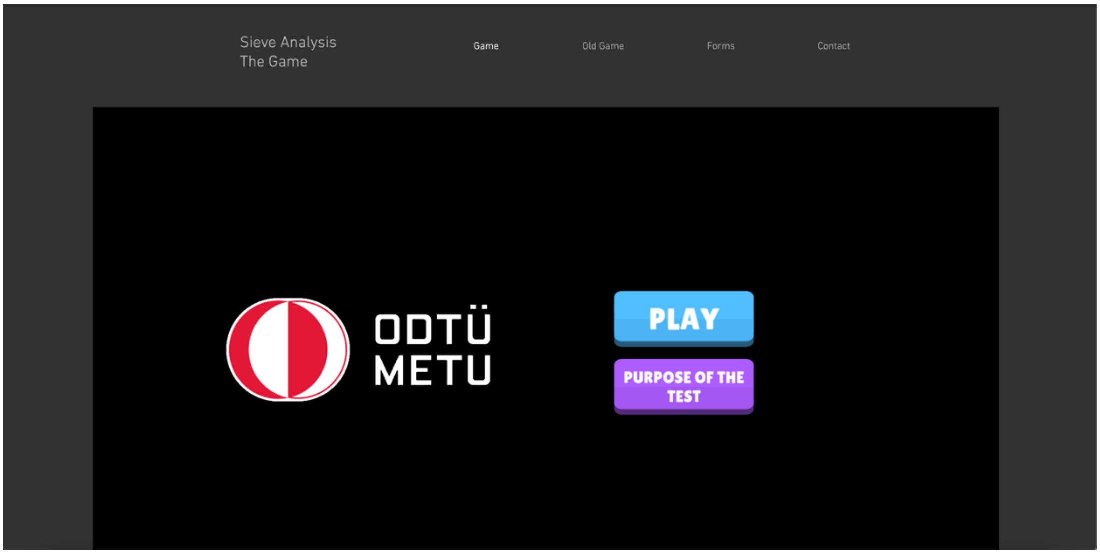


Figure 9 Screenshot of the website created for the game

## 4.3 Evaluation Methods

At the conclusion of the experiment, each participant answered all of the questions on the questionnaires, which included the Technology Acceptance Model (TAM) [17], the System Usability Scale (SUS) [11], and the Gamer Motivation Profile (GMP) [55], as well as some open-ended questions designed to assess the impact of additional items, such as “Did you read the instructions? Were they helpful?.”

### 4.3.1 Technology Acceptance Model

The Technology Acceptance Model (TAM) was first established by Frank Davis [17] in 1987 in order to answer questions such as “Why do users accept or reject information technology?.” Since that time, several approaches [30] to TAM have been developed as a result of the progression of technology throughout the course of time. [30] In order to develop a TAM questionnaire for the experiment and research objectives, a number of different studies on TAM were reviewed and analyzed. Some of these publications, such as Chau [12] and Chesney [14], concentrated on the fundamental principles of TAM, whereas others, such as Gefen and Keil [21], McCloskey [33], and Masrom [32], centered their attention on the various adaptations of TAM and the application cases that they were used in. A revised form of the TAM questionnaire is used in this study. It consists of 10 questions that are separated into two unique groups: those pertaining to perceived usefulness (PU) and perceived ease of use (PEU). The first six questions are used to measure PU, and the other four are used to calculate PEU. As the name suggests, PU is how useful users find the introduced technology. PEU is how well users can adjust to the technology in question.

Table 1 Details of the System Usability Scale from Bangor et al. [9].

| Acceptability | Grade Scale | SUS Score |
|---|---|---|
| Acceptable | A+ | 84.1 - 100 |
| | A | 80.8 - 84 |
| | A- | 78.9 - 80.7 |
| | B+ | 77.2 - 78.8 |
| | B | 74.1 - 77.1 |
| | B- | 72.6 - 74.0 |
| | C+ | 71.1 - 72.5 |
| Marginal | C | 65.0 - 71.0 |
| | C- | 62.7 - 64.9 |
| | D | 51.7 - 62.6 |
| Not Acceptable | F | 0 - 51.7 |
| Acceptability | Grade Scale | SUS Score |
| Acceptable | A | 90-100 |
| | B | 80-90 |
| | C | 70-80 |
| Marginal | D | 60-70 |
| | F | 50-60 |
| Not Acceptable | | 0-50 |

### 4.3.2 System Usability Scale

System Usability Scale (SUS) is a low-cost usability scale designed by Brooke [11] to evaluate and research the usability of a system for general assessments. The SUS comprises of 10 questions, of which fifty percent are positive-toned, and fifty percent are negative-toned. Responses are provided on a scale from 1 to 5. (Extremely unlikely to Extremely likely). Using the collected data, the SUS score is calculated, and the result falls between 0 and 100. In the study by Bangor et al. [9], a SUS scale with letter grades A, B, C, D, and F was recommended to evaluate the score. Later, Sauro [42] presented Curved Grading Scale (CGS) as an alternative method in which the curve was constructed using an extensive data set consisting of over 5000 completed SUS questionnaires. Odd numbered questions are the positive stated questions, and the even numbered questions are negative stated questions. That's why the score calculation is not the sum of all the scores. The CGS [9] was employed in this study to determine the SUS score. The score calculated according to a standard formula.

- X = Sum of the points for all odd-numbered questions – 5

- Y = 25 – Sum of the points for all even-numbered questions
- System Usability Scale Score = (X + Y) x 2.5

### 4.3.3 Presence

The experience of having one's mind in one location while their body is in another one is referred to as presence [51]. The sensation of being in a computer-generated or virtual world while physically present in the actual world is referred to as "presence," and it has been defined specifically for use in virtual environments. The level of immersion a player has while playing the game is evaluated with the help of a presence questionnaire. The questionnaire has 28 questions on a 7-point scale (1 to 7, negative to positive). The first 14 questions are all about Control, then there are 8 questions about Sensory, 5 questions about Distraction, and finally there is 1 question about Realism.

### 4.3.4 Gamer Motivation Profile

In order to determine a person's level of participation in gaming, Quantic Foundry [40] developed a set of questions that are collectively referred to as the Gamer Motivation Profile, or GMP, for short. Quantic Foundry [40] is a research company concentrating on the different factors driving gamers. However, for the aim of this research, we used a simplified version of GMP to investigate the gaming history of the participant. They are specialists in many different aspects of gaming and players. Our simplified GMP version determines whether a player is Non-gamer, casual gamer, core/mid-core gamer, or hardcore gamer.

# CHAPTER 5

# RESULTS

For descriptive analysis, t-tests, and reliability analysis, the statistical work was carried out with the assistance of the software package JASP 2020 v0.14. The categorization criteria established by Kilic [26] have accounted for reliability coefficients as one of the factors to take into consideration [21]. In accordance with the requirements for classification, both TAM dimensions may be relied upon, and SUS can be considered suitable.

Table 2 Commonly accepted classification of alpha value [22].

| Cronbach's α | Comments |
|---|---|
| $\alpha \geq 0.9$ | Outstanding |
| $0.7 \leq \alpha < 0.9$ | Good |
| $0.6 \leq \alpha < 0.7$ | Acceptable |
| $0.5 \leq \alpha< 0.6$ | Weak |
| $\alpha \leq 0.4$ | Unacceptable |

The fundamental statistical analysis of the SUS Descriptives for versions 1 and 2 of the game is shown in Table 3, which may be found below. According to the findings, version 2 of the game has a higher score regarding its usability.

Table 3 Basic statistical evaluation of the answers about SUS Descriptives.

| Version | Group | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| V1 | Civil Engineering | 85.00 | 11.23 | 3.24 |
| | Computer Science-Related | 82.50 | 9.65 | 2.79 |
| V2 | Civil Engineering | 86.25 | 9.86 | 2.85 |
| | Computer Science-Related | 88.33 | 5.67 | 1.64 |

Cronbach's α (version 1) = 0.747, and Cronbach's α (version 2) = 0.891, which shows that both tests are reliable. These results pertain to the System Usability Score.

Table 4 Reliability results of System Usability Scale, for both versions of the game.

| Version | Estimate | Cronbach's α |
|---|---|---|
| V1 | Point Estimate | 0.747 |
| V2 | Point Estimate | 0.891 |

A t-test on independent samples was used to see if the difference between the mean values of participants with a Civil Engineering and Computer Science-Related background for versions 1 and 2 of the game was statistically significant. In this study, the null hypothesis (H0) states, “The difference between the mean responses from Civil Engineering and Computer Science-Related background versions of the game is equal” (H0: CE – CS-R = 0). The alternative hypothesis (H1) is two-tailed since it requires that the difference is not zero (H1: CE – CS-R 0). Tables 5 and 6 provide a summary of the results.

Table 5 System Usability Scale - t-test Results, compared based on participants’ background, for game’s version 1.

| t | Sig. (two-tailed) | Mean Difference | Std. Error Difference | 95% CI for Mean Difference | |
|---|---|---|---|---|---|
| | | | | Lower | Upper |
| 0.58 | 0.56 | 2.50 | 4.28 | -6.37 | 11.37 |

Table 6 System Usability Scale - t-test Results, compared based on participants’ background, for game’s version 2.

| t | Sig. (two-tailed) | Mean Difference | Std. Error Difference | 95% CI for Mean Difference | |
|---|---|---|---|---|---|
| | | | | Lower | Upper |
| 0.63 | 0.53 | -2.08 | 3.28 | -8.89 | 4.73 |

Figure 9 and Figure 10 depict the box plots of the System Usability Score questionnaire results for versions 1 and 2 of the game, respectively. The box plots indicate that the scores of the Civil Engineering participants are greater than those of the Computer Science participants.

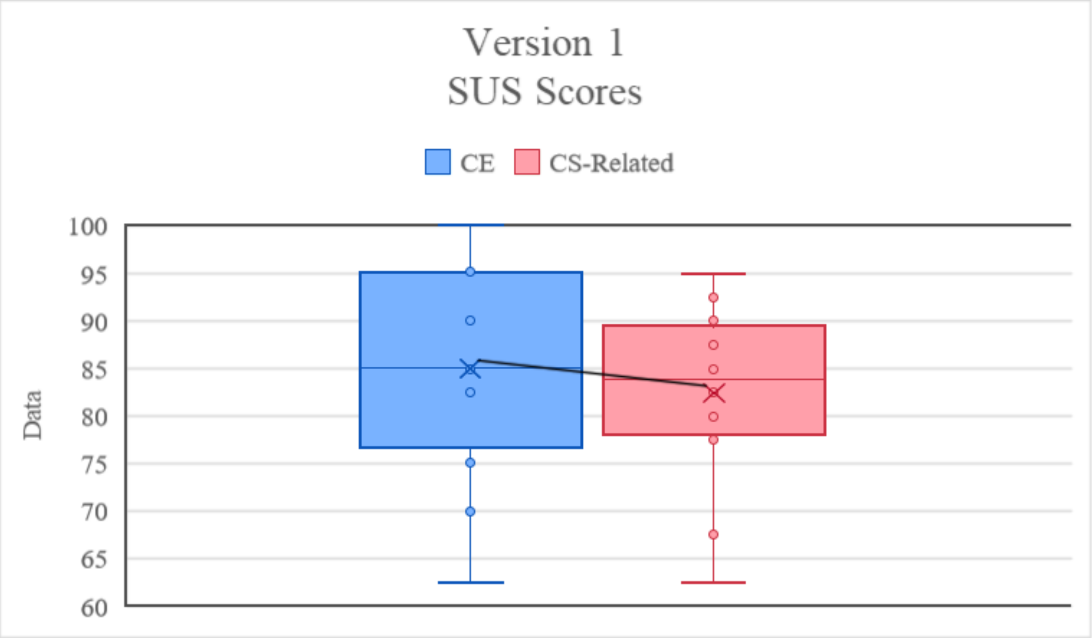


Figure 10 The boxplot of the SUS Scores for version 1 of the game.

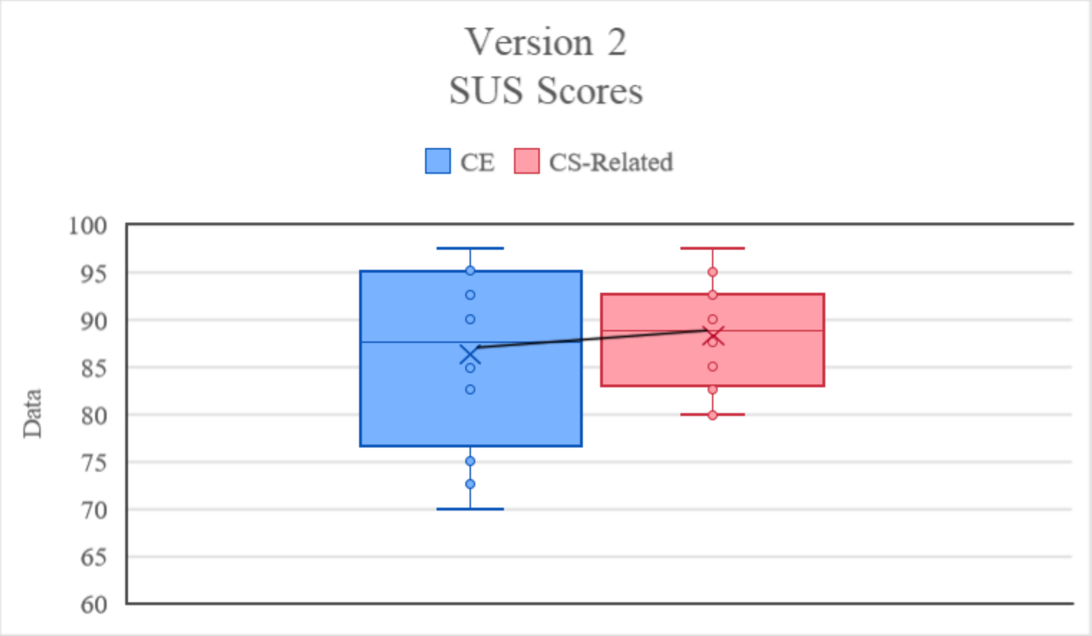


Figure 11 The boxplot of the SUS Scores for version 2 of the game.

The evaluation of the TAM Descriptors for versions 1 and 2 of the game is presented in Table 7. According to the results, version 2 of the game has a little higher TAM score.

Table 7 Basic statistical evaluation of the answers about TAM Descriptives.

| Version | Group | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| V1 | Civil Engineering | 6.19 | 0.54 | 0.16 |
|  | Computer Science-Related | 6.15 | 0.75 | 0.22 |
| V2 | Civil Engineering | 6.21 | 0.69 | 0.20 |
|  | Computer Science-Related | 6.32 | 0.63 | 0.18 |

Cronbach's α (version 1) = 0.847 and Cronbach's α (version 2) = 0.797 for the Technology Acceptance Model, showing that both tests are credible.

Table 8 Reliability results of the Technology Acceptance Model, for both versions of the game.

| Version | Estimate | Cronbach's α |
|---|---|---|
| V1 | Point Estimate | 0.847 |
| V2 | Point Estimate | 0.797 |

A t-test on independent samples was used to see if the difference between the mean values of participants with a Civil Engineering and Computer Science-Related background for versions 1 and 2 of the game was statistically significant. In this study, the null hypothesis (H0) states, "The difference between the mean responses from Civil Engineering and Computer Science-Related background versions of the game is equal" (H0: CE – CS-R = 0). The alternative hypothesis (H1) is two-tailed since it requires that the difference is not zero (H1: CE – CS-R 0). Tables 9 and 10 provide a summary of the results.

Table 9 Technology Acceptance Model - t-test Results, compared based on participants' background, for game's version 1.

| t | Sig. (two-tailed) | Mean Difference | Std. Error Difference | 95% CI for Mean Difference | |
|---|---|---|---|---|---|
|  |  |  |  | Lower | Upper |
| 0.16 | 0.88 | 0.04 | 0.27 | -0.51 | 0.60 |

Table 10 Technology Acceptance Model - t-test Results, compared based on participants' background, for game's version 2.

| t | Sig. (two-tailed) | Mean Difference | Std. Error Difference | 95% CI for Mean Difference | |
|---|---|---|---|---|---|
|  |  |  |  | Lower | Upper |
| 0.43 | 0.67 | -0.12 | 0.27 | -0.68 | 0.44 |

Figure 12 and Figure 13 depict the box plots of the TAM Perceived Usefulness questionnaire results for versions 1 and 2 of the game, respectively.

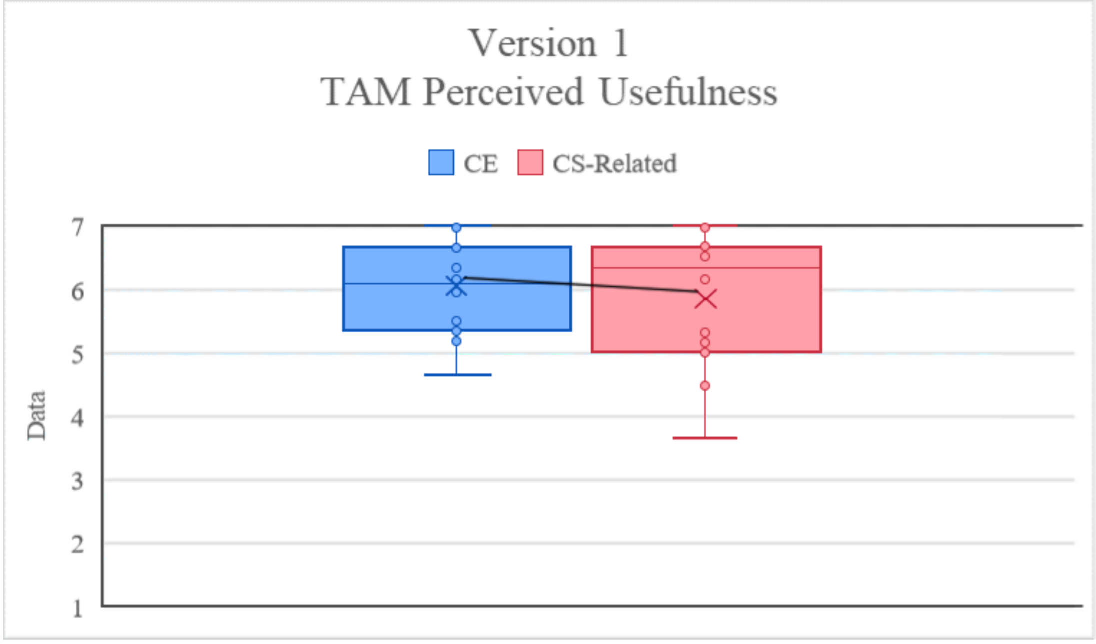


Figure 12 The boxplot of the TAM Perceived Usefulness for version 1 of the game.

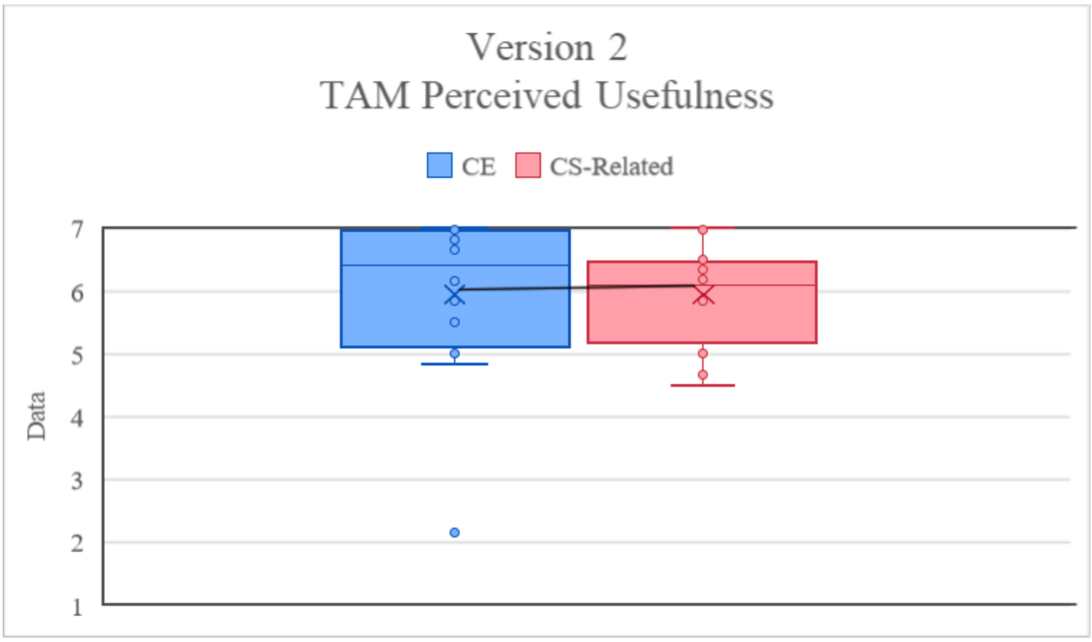


Figure 13 The boxplot of the TAM Perceived Usefulness for version 2 of the game.

Figures 14 and 15 depict the box plots of the TAM Perceived Ease of Use questionnaire results for versions 1 and 2 of the game, respectively.

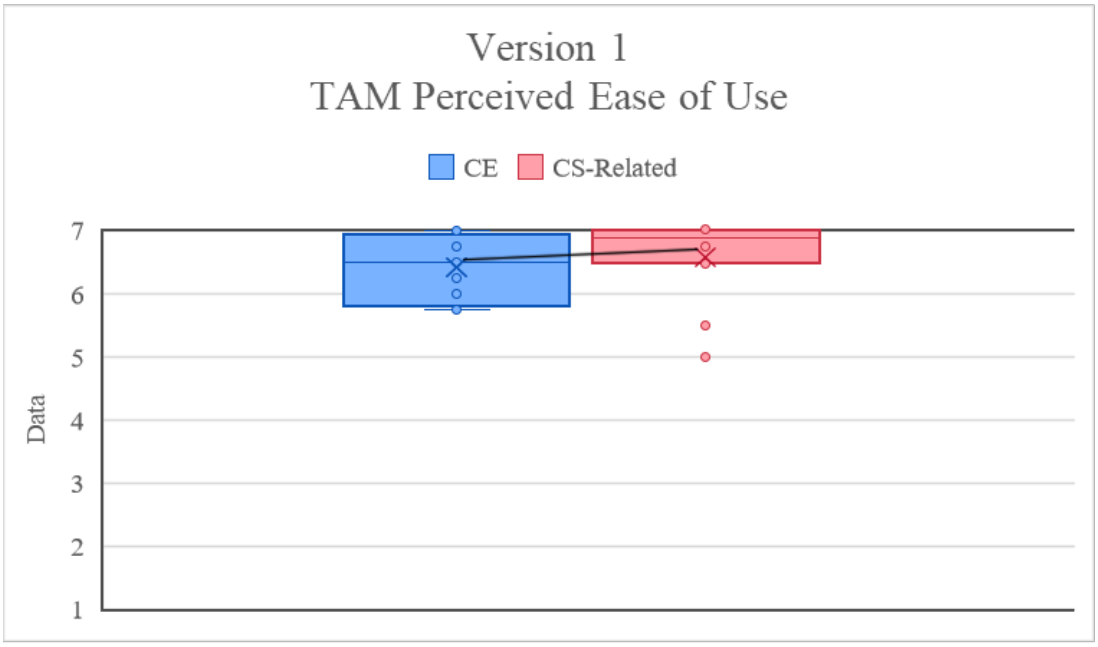


Figure 14 The boxplot of the TAM Perceived Ease of Use for version 1 of the game.

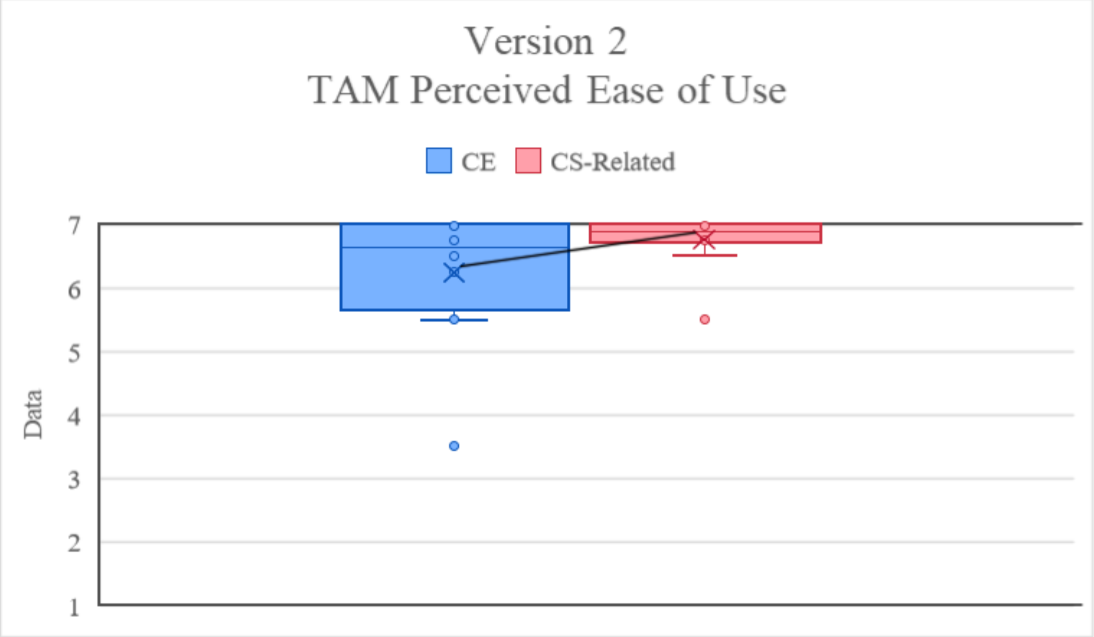


Figure 15 The boxplot of the TAM Perceived Ease of Use for version 2 of the game.

Table 11 displays the fundamental statistical evaluation of version 1 and version 2 of the game's Presence Descriptors. The results indicate that version 2 of the game has a somewhat higher score for presence.

Table 11 Basic statistical evaluation of the answers about Presence Descriptives.

| Version | Group | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| V1 | Civil Engineering | 6.13 | 0.52 | 0.12 |
| | Computer Science-Related | 6.17 | 0.71 | 0.21 |
| V2 | Civil Engineering | 6.22 | 0.64 | 0.26 |
| | Computer Science-Related | 6.33 | 0.56 | 0.15 |

Cronbach's α (version 1) = 0.648 and Cronbach's α (version 2) = 0.848 for the System Usability Score, showing that both tests are credible.

Table 12 Basic statistical evaluation of the answers about Presence Descriptives.

| Version | Estimate | Cronbach's α |
|---|---|---|
| V1 | Point Estimate | 0.648 |
| V2 | Point Estimate | 0.848 |

Figure 16 and Figure 17 depict the box plots of the Presence questionnaire results for versions 1 and 2 of the game, respectively.

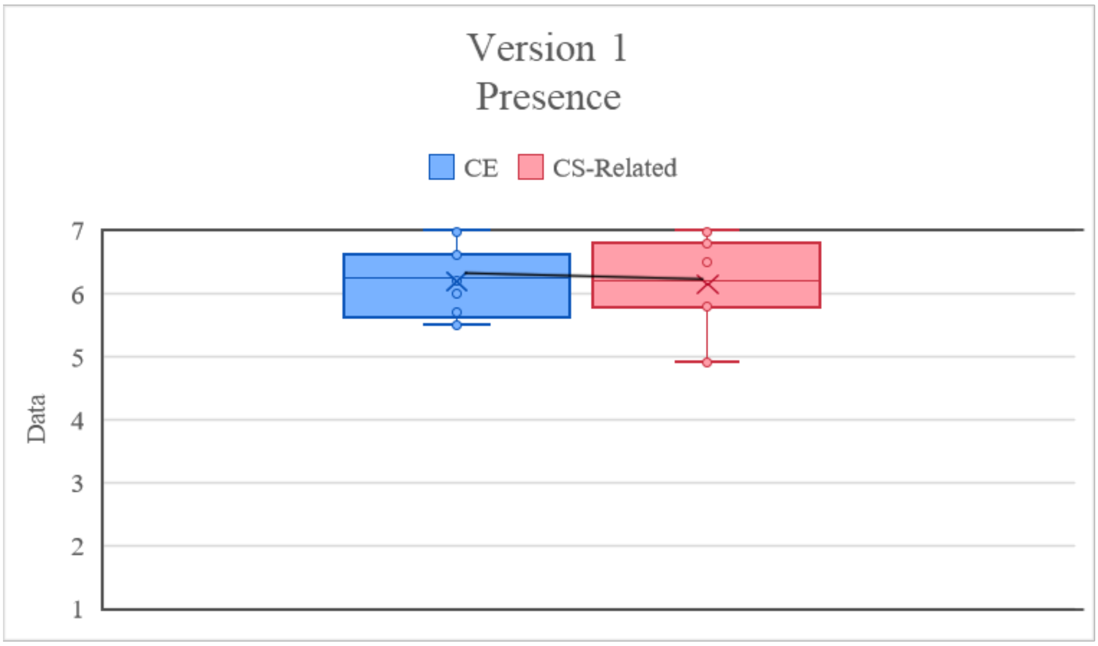


Figure 16 The boxplot of the Presence Scores for version 1 of the game.

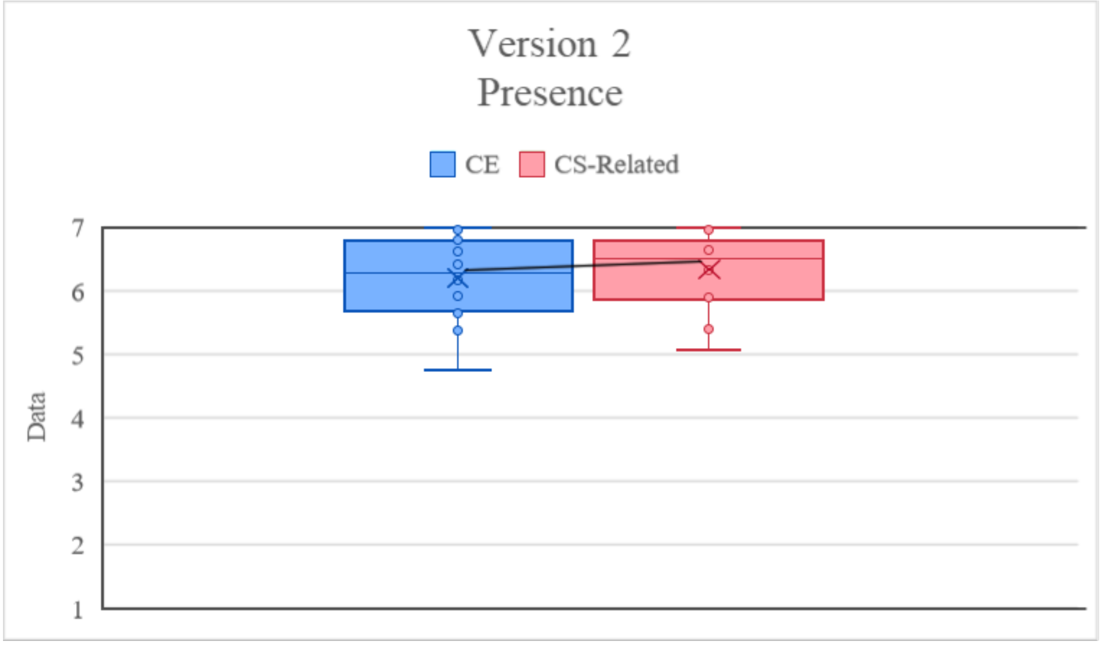


Figure 17 The boxplot of the Presence Scores for version 2 of the game.

There are seven categories for which SUS scores are calculated: overall score, civil engineering score, computer-related score, non-gamer score, core/mid-core gamer, casual gamer, and hardcore gamer. As previously noted, the CGS scale was utilized to evaluate these scores. For version 1, the overall score and computer science-related testers get an A, civil engineers testers get an A+, for the second version, all three categories scored an "A+," and all categories improved scores. (Figure 18). When SUS scores were checked according to the GMP of the testers. For the first version, hardcore gamers scored a B, casual gamers scored an A, and core/mid-core gamers and non-gamers scored an A+. For the second version, hardcore gamers and casual gamers scored an A, and core/mid-core gamers and non-gamers scored an A+. (Figure 19) All scores are improved, but casual-only hardcore gamer grades changed from B to A in the second version.

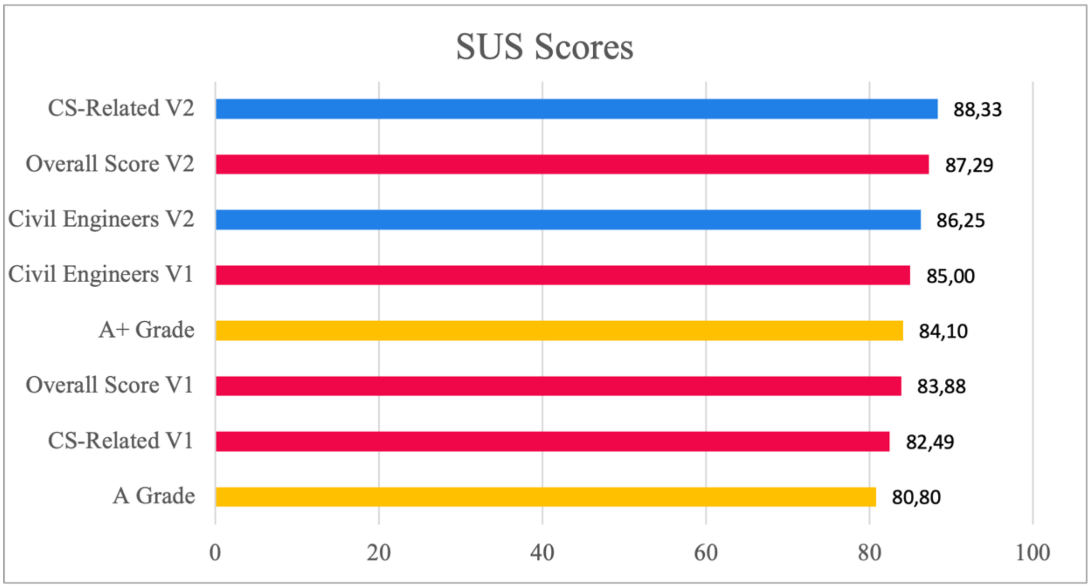


Figure 18 SUS scores on CGS scale based on departments.

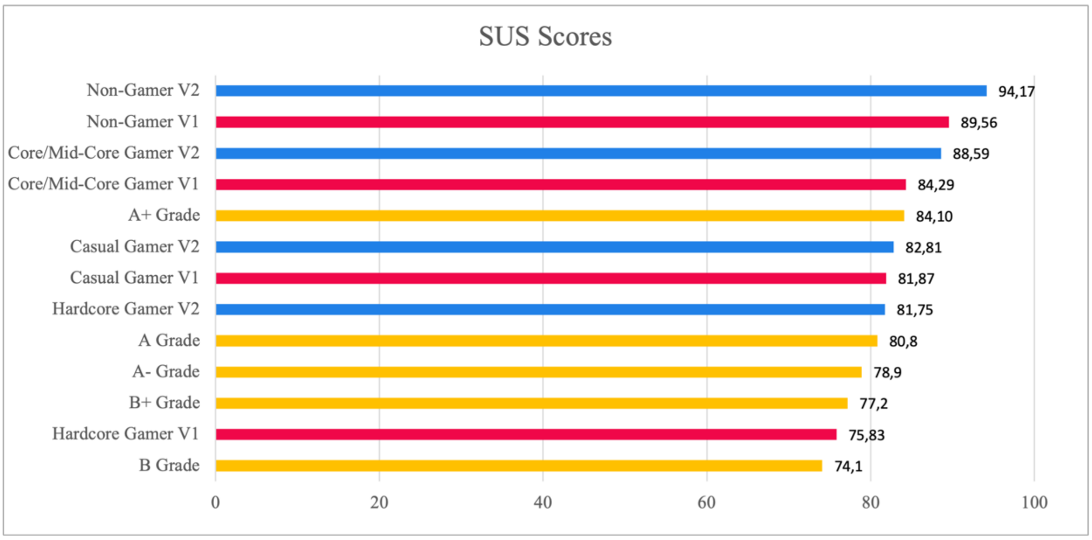


Figure 19 SUS scores on CGS scale based on gamer profiles.

Table 13 compares the CPU consumption between versions 1 and 2 of the game, Table 14 compares the memory usage, and Table 15 compares the render parameters. SetPass Calls, Draw Calls, Total Batches, Triangles, and Vertices are parameters utilized by the rendering profile. On the Renderer Profiler page of Unity, the SetPass parameter is described as “the number of rendering passes,” the Draw Request parameter as “a request to the graphics API to draw objects,” and the Batch parameter as “a group of data that will be delivered to the GPU.”

Table 13 CPU usage for version 1 and version 2 of the game.

| CPU usage | Version 1 (ms) | Version 2 (ms) |
|---|---|---|
| CPU | 7.5 | 6.1 |

Table 14 Memory usage for version 1 and version 2 of the game.

| Memory | Version 1 (GB) | Version 2 (GB) |
|---|---|---|

| | | |
|---|---|---|
| Used total | 0.61 | 0.58 |
| Reserved total | 0.80 | 0.80 |
| System memory usage | 2.25 | 1.29 |

Table 15 Rendering parameters for version 1 and version 2 of the game.

| Rendering | Version 1 | Version 2 |
|---|---|---|
| SetPass calls | 46 | 84 |
| Draw calls | 734 | 137 |
| Batched draw calls | 0 | 325 |
| Total batches | 734 | 203 |
| Triangles (K) | 102.2 | 98.2 |
| Vertices (K) | 128 | 124.2 |

# CHAPTER 6

# DISCUSSION

This study aimed to develop a workable solution to the shortage of laboratory experiment opportunities in online education. Twenty-four users' data were examined to determine the outcome of the framework's virtual soil mechanics laboratory. According to the results of the TAM and SUS questionnaires, the technique under consideration would be beneficial and might aid students who cannot work in a laboratory due to COVID-19 restrictions or a lack of equipment. This experiment demonstrated that utilizing the framework was useful as well. According to the game analytics dashboard, version 2 of the virtual laboratory experiment was done properly; none of the testers identified any flaws or defects that would harm the enjoyment of the game. The dashboard also indicates that the experiment was successful.

After the test of the first version was completed, it was decided that an alternative, improved version should be developed. To do so, we analyzed the results and comments from version 1. The most important problem was the UI of the game. It was discovered that users misinterpreted the instruction on the screen for a banner advertisement and opted to ignore it when it was displayed in version 1 as white letters on a gray background with a score section at the bottom. Some adjustments had to be made in order to correct this misleading perception. The color of the action buttons has been changed from orange to yellow, and purple has been used across the user interface rather than gray to provide contrast between the game environment and UI. Instruction texts and the current score are displayed at the very top of the screen. In addition, the information button located above the action button was taken out of the second version of the game and replaced with a single button in the primary user interface. It was decided to use white text on a blue and red background for this information button to make it easier for players to detect. In contrast to the previous iteration, the onboarding process for new players consisted of a five-step tutorial. To begin, we gave players an overview of the game by centering an animated circle around elements that should be interacted with and providing additional information. At the beginning of the game, the players were shown the score, the action button, the instruction text, and the information button. The action button came first, followed by the instruction text, score, and information buttons. After that, we showed players how to use the action button, which was the only button on the screen from which they did not have to choose. This was done to ensure that players had a clear understanding of how to interact with the environment of the game. The game scenario went through several iterations of restructuring, and several of the game's options found unclear to players during testing were removed. When the game was first granted access to players, it was not clear to them which item the action buttons that were located next to each other belonged to. As a result, the alternatives were altered to make them more understandable.

According to Table 8, both PU and PEU's TAM results have Cronbach's coefficients greater than 0.7, showing that both are credible. The TAM data were analyzed using a t-test on independent samples. Levene's test findings were more than 0.05 (Table 9-10), indicating that the test is insignificant, and the null hypothesis cannot be rejected. The null hypothesis stated that both groups viewed the game similarly. The mean values of the null hypothesis follow a similar trend. Given that the mean difference between PU and PEU is less than 5%, we may assume that civil engineers and students in subjects connected to computer science had similar perceptions of the virtual laboratory.

When the results of Table 2 were analyzed, the SUS test results have Cronbach's coefficient in the range, which places them in the good category and makes them credible. According to Table 3 and Table 4, Levene's test findings were more than 0.05, which means the null hypothesis cannot be rejected, just like TAM results. As before null hypothesis stated that both groups viewed the game similarly.

Cronbach's coefficients for Presence Descriptive are quite different between the two versions. (Table 12) One result is smaller than 0.7 and greater than 0.6, so it puts the results acceptable but unreliable category.

Version 1 of the virtual laboratory experiment earns a SUS score of 83.88 and an A on the Curved Graph Scale (CGS), whereas version 2 earns a SUS score of 87.29 and an A+ on the CGS. Even though version 1 scored an A on CGS, optimizations and improvements on version 2 improved the score to an A+. With the help from GMP, we analyzed the scores from each gamer profiles. Hardcore gamers scored in version 1 75.83, which is a B and their score increased in the second version by 81.75, which takes their score to an A. Casual gamers' score increased 0.94 points from 81.87 to 82.81, which keeps their scores as an A. Casual gamers' scores had the minimum improvement among all four-gamer profiles. Core/mid-core gamers' scores increased from 84.29 to 88.59 keeping them at A+, and non-gamers' scores increased from 89.59 to 94.17, keeping them the best scores for both versions.

When a comparison is made between departments for both versions in terms of SUS scores, although the lowest of these three scores for version 1 is 82.49, which is an A grade, the score decreases as the user's interaction with games and computers matures. The major audience for this virtual laboratory experiment, civil engineers, scored 85, awarding it an A+ grade and proving the game's success. Due to the fact that the data is only acceptable to CGS, a larger study of SUS with more participants may improve the test's and results' reliability. The lowest of these three scores on version 2 is 86.25, indicating that all scores on this version are A+ ratings. The score of civil engineers only increased by 1.25 points, whereas the scores of computer science-related disciplines increased by 7.61 and 5.84 points, respectively. With gains in both categories, the total score has increased by 3.41. After the second experiment, all participants were asked if the second version was beneficial; all participants responded affirmatively, which reflected positively on their ratings. Since civil engineers had laboratory experience with sieve analysis, the tutorial execution impacted their scores less than others.

In this experiment, a single soil particle became stuck on the sieve, and the participants used the brush tool to remedy the situation. A few participants familiar with the sieve analysis test remarked that this characteristic was advantageous to the learning process due to its rarity. This is a quality benefit of virtual laboratories that can be implemented with this framework: the capacity to replicate the experiment's uncommon settings.

The initial version of the game that was developed, which can be seen in Figure 6, had the words “Next task:2 contained on the bottom left corner of the screen. This was previously described. In the first survey we gave to our participants, we asked them, “Did you read the instructions? If so, were they helpful?.” Eight of them responded that they had read the instructions and found them helpful, while nine stated that they did not notice the instructions until after they had completed certain tasks. After they had observed it, it was beneficial to them; nevertheless, the remaining seven participants did not recognize any instructions on the screen. The percentage of people who were not aware that instructions were included is a significant factor to consider. After the game, several players who did not notice the instruction text said they had misunderstood the instruction panel as an advertisement banner. There are a number of theories as to why people see it as a banner advertisement rather than performing the job for which it was originally intended; nonetheless, this subject needs to be investigated further. Creating a user interface that is more immersive within the simulation environment is one way that Llanos and Jrgensen [29] propose to overcome this problem. While we were working on the second iteration, we looked at the feedback from the beta testers to formulate our hypotheses about why the user interface (UI) was so difficult to understand.

*“I am uncertain, but I believe there was previously no action button. I thoroughly enjoyed it. It was quite helpful because it displayed options and prevented me from clicking around to determine what to do.”*
*“I observed that in this version, players are guided by directions and action buttons have been placed. Undoubtedly, the experience has been improved.”*
*In this version, I was able to interact with the user interface more naturally.*
*“A button was placed to the right side of the screen from which I could access item details. This made me feel more relaxed.”*
*“The new edition of the game responds to my actions considerably more quickly than its predecessor.”*
*“Tutorial had a significant impact on my experience, as I had never encountered such a laboratory before.”*
*“Yes, I have observed numerous improvements. I had more control over the atmosphere on the second test, thus I fared better than on the first.”*

In conclusion, participants provided meaningful feedback in reference to the suggested system’s comparison to traditional laboratory courses. They found the proposed system to be practical and adaptable in terms of informing users about the requirements, scenarios, and decision-making for the laboratory session. They argued for the utilization of this laboratory setting as a teaching tool for a variety of different classes. Accessibility for all was also emphasized as an essential component of the system, highlighting the need to provide a low-cost virtual environment with different roles that are required. The technology has several advantages, including immersion, realism, and the blending of the real and virtual worlds.

# CHAPTER 6

# CONCLUSION AND FUTURE WORK

The majority of engineering courses incorporate laboratory work as part of their curriculum. Online laboratory practice reinforces the course material when physical learning is not possible, like in the case of the pandemic or when the educational environment conditions are not responding to the needs of the students, and we cannot meet this demand through actual laboratory sessions. According to the many studies in this area, virtual laboratories have proven effective in these scenarios [43], allowing students to get regular, inexpensive, and fun training.

This research focuses on developing a generic, modular virtual laboratory framework that enables game designers and developers to build lab experiments as serious games without having to write additional programming. The modular nature of the framework makes it easy for developers to add new features with minimal effort. Within the framework, a virtual lab for the soil mechanics course in civil engineering was developed and tested by 24 participants, 12 of whom held degrees in the Civil Engineering Department and the remainder in Computer Science-Related fields. The research was conducted in two parts, with participants testing two versions of the game, with the second version incorporating participant comments.

The results from the developed and tested games are evaluated by three standard usability surveys; the Technology Acceptance Model measuring the acceptability of the system by the users, the System Usability Scale measuring the ease of the virtual laboratory for the users, and Presence testing the involvement quality of the end users.

SUS mean scores increased for the second version. Presence mean scores stayed almost the same for civil engineers and increased for computer science-related testers. TAM mean scores increased for both departments. Also, the results indicate that the produced games, especially version 2 has the ability to create interactive virtual labs, and the framework’s modular design enables a number of applications.

Within the scope of this research, three standard usability surveys are done to evaluate the results. Measuring the usability of the generated games was the main purpose of this study; it can be enhanced by testing the framework in terms of these three standard usability surveys. This way, the content, and the developed system can be evaluated in further research. Thus, this framework can be applied and used in various fields.

During this research, the focus was only on the sieve analysis experiment from the soil mechanics course of the civil engineering department. For more accurate and detailed results in the usability of the virtual laboratory generation framework, more laboratories should be generated and tested. Only this way can more comprehensive results can be achieved.

Testers' results and comments hint at generated virtual laboratories’ effect on learning. However, this research’s main focus was on measuring the usability of the framework. In the future, a more elaborate study should be made to measure the effect on learning.

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# APPENDICES

## APPENDIX A

## ADAPTED TECHNOLOGY ACCEPTANCE MODEL QUESTIONNAIRE

Please place an “X” in the appropriate box to rate the following items using scale of 1–7: 1= Extremely Unlikely 7=Extremely Likely

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| **Perceived Usefulness** | | | | | | | |
| Using this game in my education would enable me to perform lab experiments more quickly. | | | | | | | |
| Using this game would improve my class performance. | | | | | | | |
| Using this game in my education would increase my productivity in lab. | | | | | | | |
| Using this game would increase my effectiveness in class. | | | | | | | |
| Using this game would make it easier to study my class. | | | | | | | |
| I would find this game useful as a supplementary material. | | | | | | | |
| **Perceived Ease of Use** | | | | | | | |
| Learning to play this game is easy for me. | | | | | | | |
| My interaction with this game is clear and understandable. | | | | | | | |
| It would be easy for me to become skillful at playing this game. | | | | | | | |
| I would find this game easy to play. | | | | | | | |

# APPENDIX B

## SYSTEM USABILITY SCALE

Please place an “X” in the appropriate box to rate the following items using scale of 1–5: 1= Strongly Disagree 5=Strongly Agree

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| I think that I would like to play this game frequently. | | | | | |
| I found this game unnecessarily complex. | | | | | |
| I thought this game was easy to play. | | | | | |
| I think that I would need assistance to be able to play this game. | | | | | |
| I found the various functions in this game were well integrated. | | | | | |
| I thought there was too much inconsistency in this game. | | | | | |
| I would imagine that most people would learn to play this game very quickly. | | | | | |
| I found this game very cumbersome/awkward to play. | | | | | |
| I felt very confident playing this game. | | | | | |
| I needed to learn a lot of things before I could get going with this game. | | | | | |

# APPENDIX C

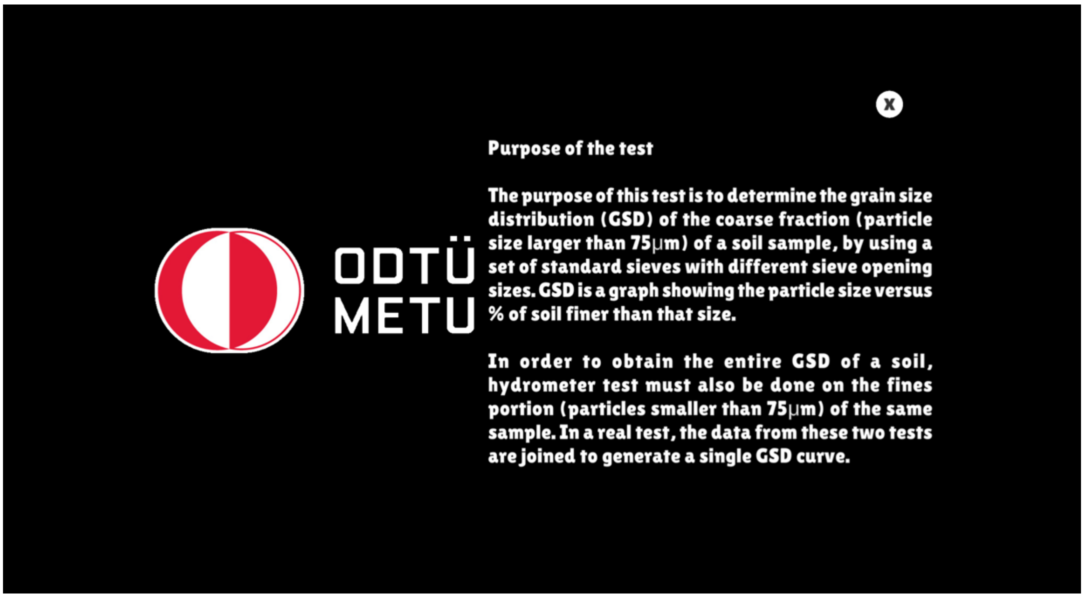
## PRESENCE

Please place an “X” in the appropriate box to rate the following items using scale of 1–7: 1= None 7=A lot

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| How much were you able to control events? | | | | | | | |
| How responsive was the environment to actions that you initiated (or performed)? | | | | | | | |
| How natural did your interactions with the environment seem? | | | | | | | |
| How much did the visual aspects of the environment involve you? | | | | | | | |
| How compelling was your sense of objects moving through space? | | | | | | | |
| How much did your experiences in the virtual environment seem consistent with your real world experiences? | | | | | | | |
| Were you able to anticipate what would happen next in response to the actions that you performed? | | | | | | | |
| How much delay did you experience between your actions and expected outcomes? | | | | | | | |
| How much did the visual display quality interfere or distract you from performing assigned tasks or required activities? | | | | | | | |
| How much did the control devices interfere with the performance of assigned tasks or with other activities? | | | | | | | |
| How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities? | | | | | | | |
| Were you involved in the experimental task to the extent that you lost track of time? | | | | | | | |

# APPENDIX D

## In-game screenshots

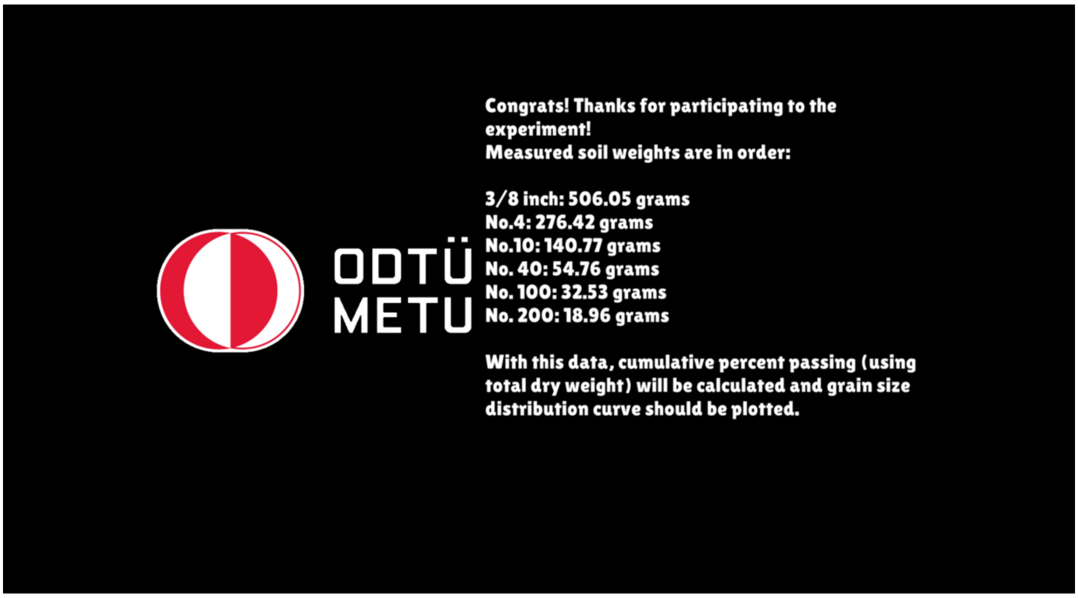


**Purpose of the test**

The purpose of this test is to determine the grain size distribution (GSD) of the coarse fraction (particle size larger than 75μm) of a soil sample, by using a set of standard sieves with different sieve opening sizes. GSD is a graph showing the particle size versus % of soil finer than that size.

In order to obtain the entire GSD of a soil, hydrometer test must also be done on the fines portion (particles smaller than 75μm) of the same sample. In a real test, the data from these two tests are joined to generate a single GSD curve.

Figure 20 Purpose of the test screen



Congrats! Thanks for participating to the experiment!
Measured soil weights are in order:

3/8 inch: 506.05 grams
No.4: 276.42 grams
No.10: 140.77 grams
No. 40: 54.76 grams
No. 100: 32.53 grams
No. 200: 18.96 grams

With this data, cumulative percent passing (using total dry weight) will be calculated and grain size distribution curve should be plotted.

Figure 21 End game measurements

Figure 22 Stuck piece simulation