Hari Bhusal

Impact of Augmented Reality Sandbox on user Interactivity and Engagement

Master's thesis in Electronic Systems Design and Innovation
Supervisor: Andrew Perkis
Co-supervisor: Wendy Ann Mansilla Obiri
September 2023

Master's thesis

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I am grateful to my supervisor, Professor Andrew Perkis, for his guidance, feedback, opportunities, and continuous support throughout my thesis. I would also like to thank my co-supervisor Wendy Ann Mansilla Obiri for providing all the necessary resources, supervision, and support during the entire period. I would also like to give my thanks to Ana Sanchez Laws for her support during my thesis. My thanks also go to Øyvind Sørdal Klungre for his support at the Sense-IT lab. Lastly, I would also like to give thanks to the technical staff Erling A. Bakken Jacobsen, Christer Nesset, and Morten Ekeberg at NTNU for helping me to make the frame for AR Sandbox. Last but not least, I would like to express my deep love to my family for their constant support and encouragement during my academic path. Their love, patience, and understanding have been my pillars of strength, allowing me to pursue and accomplish this thesis.

Abstract

Augmented Reality (AR) technology combines real-world and digital elements to provide users with a unique and immersive experience. This study explores the impact of an AR Sandbox on user interactivity and engagement. We investigate the implementation and installation of AR Sandbox technology, covering the technical complexities and setup processes. Our validation and assessment methodical approach is using testing, and data collection through Likert-Scale questionnaires with active participants. By systematically aligning our findings with concepts gathered from a diverse array of literature, we depict the dynamic interplay between AR technology and user experiences. Our study employs descriptive statistics to evaluate user engagement and interactivity facilitated by AR Sandbox technology. Findings show that while AR Sandbox technology has the potential to enhance user engagement and interactivity, its impact is mitigated by factors such as the absence of playful features. This study not only gives useful insights into the growing landscape of augmented reality technology but also lays the way for future inquiries and advances, notably in the education and outreach sectors.

Keywords: Augmented Reality; Augmented Reality Sandbox; Interactivity; Engagement; Immersion

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Abbreviations

XR Extended Reality

AR Augmented Reality

MR Mixed Reality

VR Virtual Reality

TAM Technology Acceptance Model

UI User Interface

UX User Experience

GPU Graphics Processing Unit

PC Personal Computer

JASP Jeffreys' Amazing Statistics Program

SPSS Statistical Package for the Social Science

EDA Electrodermal Activity

GEQ Game Engagement Questionnaire

1 Introduction

1.1 Background

It is not surprising that we are currently experiencing ongoing technical advancements, a rapid increase in globalization, and other changes in the social, economic, cultural, and environmental aspects of modern life. We find it impossible to fathom a world without technology since it has already been assimilated into our daily lives. The world in the 20^{th} century has been greatly influenced by several technical advancements, including artificial intelligence, nanotechnology, machine learning, robots, biotechnology, and many more. The introduction of these new technologies is crucial at all levels of study.

While a technology known as Extended Reality (XR) encompasses both the real world and the virtual world. As a result of recent technological advancements that have resulted in lighter, more affordable hardware and software that is vastly more powerful than previous generations, there has been an increase in interest in XR among scientists and business leaders over the last five years [9]. The given Figure 1 indicates the reality and virtuality continuum which covers different areas such as Real Environment, Augmented Reality(AR), Mixed Reality(MR), and Virtual Reality(VR).

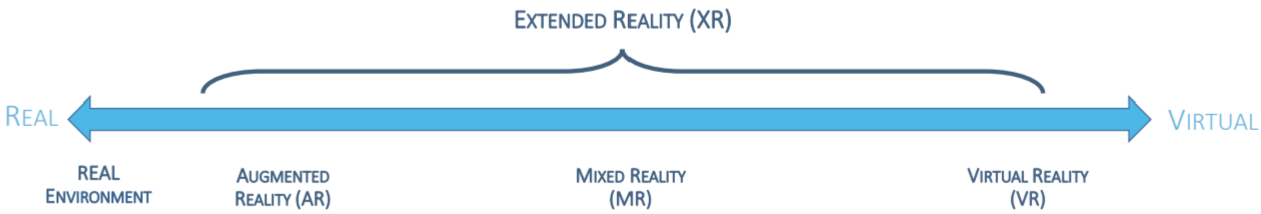


Figure 1: Reality-Virtuality Continuum Schematic [4].

Out of these areas, this study focuses more particularly on a technology called Augmented Reality (AR). When Thomas Preston Caudell, a Boeing researcher, invented an industrial application for viewing assembly drawings in 1992, he coined the term Augmented Reality (AR). The core purpose of AR is to create linkages between the physical environment and any technical or device-generated information, either directly or through user engagement with the device [2]. Over the past ten years, AR has grown quickly, drawing major research and development from both academia and business [25]. AR can be applied to different technologies, such as marker-based AR and markerless AR [8] in which location-based and projection-based are included in it. AR has established itself as a significant player in a number of fields, including entertainment, education, medicine, architecture, tourism, business, and many more. For instance, the most popular AR-based game is Pokemon GO, which we may use as an example [22]. Augmented reality (AR) is poised to become the upcoming technological platform that exerts significant societal influence, akin to the transformative effects witnessed with the advent of the initial major digital platform, the World Wide Web, and the subsequent platform, mobile social media [21].

There are different ways to illustrate the AR technology. Among them, Augmented Reality(AR) Sandbox is one of the popular AR technologies which is the main focus and objective of this research. It is a 3D interactive and dynamic tool that has the capacity to overlay the virtual information into the real physical environment such as sand. Due to its intuitive and interaction-enhancing haptic operation, it has been employed as a valuable tool for science and teaching [33]. In this study, we will discuss the idea behind the AR Sandbox, its origin, setup and calibration, and software installation in this study. We will also examine the influence of AR Sandbox on the amount of interactivity and engagement among users via the test and responses from them via a questionnaire. Following that, we will demonstrate the key characteristics of our study, interaction, and engagement with a variety of articles related to AR technology and the AR Sandbox to support our findings.

1.2 The AR Sandbox and it's origin

The "UC Davis" W.M. Keck Center for Active Visualization in the Earth Sciences [26], along with the UC Davis Tahoe Environmental Research Center [32], Lawrence Hall of Science, and ECHO Lake Aquarium and Science Center, involved in a National Science Foundation project on informally educating people about freshwater lake and watershed science. As part of this project, they are mainly creating 3D visualization tools to explain earth science concepts. They have also constructed an interactive exhibit combining a real sandbox and a combination of simulated topography and water, which was made using a Microsoft Kinect 3D camera, powerful simulation and visualization software, and a data projector. The exhibit was designed to be hands-on and engaging. The goal of this project was to use 3D visualizations to improve people's understanding of and commitment to protecting freshwater lake ecosystems. The AR sandbox prototype developed at UC Davis KeckCAVES allows users to learn about geographic, geologic, and hydrologic concepts by molding real sand to construct topographical models that are supplemented in real-time with an elevation color map, topographic contour lines, and simulated water. This interactive tool helps people understand concepts such as how to interpret a topography map, the significance of contour lines, and the roles of watersheds, catchment areas, and levees in the environment [26]. The developed AR Sandbox was created by Peter Gold, a project specialist from the UC Davis Department of Geology. The driving software for the sandbox was developed using the Vrui VR development toolkit [18] and the Kinect 3D video processing framework, which is open source software licensed under the GNU General Public Service [26].

1.3 Objectives

In this research, we conduct a thorough examination of Augmented Reality Sandbox technology and its impact on user engagement and interactivity. Our research is motivated by the following objectives:

i. Investigate the influence of Augmented Reality Sandbox on user engagement and interactivity.

ii. Compare and contrast findings across various studies related to augmented reality technologies to identify similarities and differences with our research with key elements interactivity and engagement.

1.4 Research Question

To meet the aforementioned goals, a research question was proposed that provides an answer to the influence of AR Sandbox on user engagement and interactivity.

1. Can Augmented Reality Sandbox influence the level of interactivity and engagement of the users?

Addressing our research question, we'll use user testing with the AR Sandbox and Likert-scale responses. We'll also compare findings from different papers to connect elements like interactivity and engagement, highlighting similarities and differences.

2 Theory and Literature Review

The core principles of interactivity and engagement, which form the backbone of our study, will be our primary focus in this section. Understanding the theoretical underpinnings of these concepts is essential to contextualize our research and its relevance within the broader landscape of interactive technology and user engagement. We will begin by discussing the theoretical framework surrounding interactivity and engagement, followed by a comprehensive comparison of relevant studies and papers. This comparative analysis will serve as a valuable reference point as we explore the interplay between these elements in the subsequent discussion section.

2.1 Interactivity

There are numerous definitions of interactivity. It is an ambiguous concept. An interaction is anything that a human does to or with another human. Alternatively, everything that involves human interaction with technology is referred to as human-technology interaction. The study [31] dissects "interactivity" into two dimensions: interpersonal interaction and interaction between people and technology. The former emphasizes the process, while the latter centers on outcomes. This distinction holds significance for research and measurement. Investigating interactivity as a process involves scrutinizing human engagement, whereas exploring interactivity as a product delves into user interactions with technology. In the context of fields like citizen involvement through technology, the understanding of interactivity bears relevance. The paper [30] investigates how students interact in the lab where the AR Sandbox is located. According to the author, students are more engaged when they work in silence rather than when they converse off-topic. Therefore, it suggests that people can interact with the elements of technology when they are deeply engaged or immersed in technology.

According to [15] interactivity is present, in a time-based setting is experienced by individuals in the world even when communication technology is involved. Although virtual embodiment may be possible, within the technology the involvement of our bodies remains crucial for interaction. Therefore based on this theory it can be concluded that physical actions are necessary for interactivity to occur.

2.2 Immersion

The term immersion is a broad concept. We use the term "immersion" to refer simply to what the technology offers from an objective standpoint. The more a system can deliver representations (across all sensory modalities) and tracking with accuracy comparable to real-world sensory experiences, the more it may be described as "immersive" [29]. The concept of immersion has been considered in many contexts but it is most commonly used for different AR and VR games and software. According to [18], for gamers, immersion is used to describe the degree of engagement or involvement with the game. This involvement evolves throughout time and can be influenced by several obstacles such as certain human actions like focus to overcome, while others are controlled by the game itself, such as its design. This study revealed three levels of involvement/engagement: initial engagement, progressing to deeper engrossment, and finally reaching complete immersion [18].

The study [13] defines immersion as the reader's state of being fully absorbed in a narrative, characterized by a trance-like reading experience where cognitive capacities are wholly engaged. It underscores how well-defined schemas and narrative predictability contribute to this immersive engagement, offering readers a sense of escape and captivation within the literary world. The author [17] aims to numerically and precisely characterize the immersion encountered during gaming. The research findings indicate that during gameplay, the sense of immersion can be evaluated both through subjective means (questionnaires) and objective measures (such as task completion duration and eye movement patterns). Additionally, the author asserts that the immersion encounter can encompass both positive and negative dimensions. The author [14] analysis of forum data highlights two distinct perspectives on immersion in board games. Some players concentrate on the features that improve immersion in specific games, whereas others seek to comprehend the concept of immersion itself through personal gameplay experiences. The findings of this study point to two overarching categories: "Conditions of Immersion," which cover factors required for immersion, and "Experiences of Immersion," which detail the characteristics of immersive gameplay.

2.3 Engagement

The term engagement is derived from the concept of immersion. Engagement encompasses every aspect of an experience that genuinely captivates individuals, whether it's the immersive feeling while engrossed in a compelling book, the thrill of overcoming challenges in an engaging game, or the enthralling narrative development in a radio drama [5]. According to [3], user engagement is a multidimensional and complicated phenomenon and is the behavioral and emotional interaction that can exist between a user and a resource at any time. The paper [29] classified user engagement into three types: user-brand engagement, user-user engagement, and user-bystander engagement.

As stated in the paper [28], flow theory is used to explain player engagement while playing the games. The application of self-determination theory extends to various human behaviors and may offer insights into engagement in digital entertainment games [12]. The Technology Acceptance Model (TAM) [11] is another theory relevant in clarifying why people participate in gaming within the field of engagement research. TAM, which was created to explain the determinants of technology acceptance in work and training situations, highlights two essential factors: perceived utility and perceived ease of use. While simplicity of use might help us understand why people play entertainment games, it's vital to remember that the importance of perceived utility varies when examining game acceptability for leisurely engagement. The study [25] focuses on the impact of the design of AR application on the engagement and interaction of users. The author uses the AR application prototype to visualize the application design concept and evaluate its impact on human engagement and interaction. The paper finds that User Interface(UI) and User Experience(UX) play a vital role in the engagement of users.

2.4 Literature review of research works

This section offers an overview of relevant research papers that examine the impact of Augmented Reality (AR) and Augmented Reality (AR) Sandbox technology on user interactivity and engagement. The following table will provide a synthesis of these research activities, including their titles, brief descriptions, methods, and outcomes relating to the major elements of our study: interactivity and engagement. This collection of studies provides to contextualize our study's findings and highlights the existing landscape of knowledge in this topic.

Elements	Paper	Description	Method	Result
Interactivity	Distributed spatial Sensemaking on the augmented reality sandbox [16].	This paper examines how the small groups collaborate on the AR sandbox to learn about topographical concepts.	The paper uses interaction analysis to analyze the groups of students who interact with the AR Sandbox in a science museum by using video recording and interviewing.	The paper shows that the groups use gestures, speech, gaze, and sand manipulation to interact with the sandbox.
	Open AR Sandbox: A haptic interface for geoscience education and outreach [33].	The paper shows how AR-sandbox can be used to visualize various geoscientific concepts and enable haptic interaction with the projected content.	The study implements an AR-sandbox system with a link to a 3-D geomodelling system using Python-based open-source software. In addition, ArUco-marker detection is used in the paper to enable more precise and flexible interaction.	Because of its intuitive and haptic interaction-enhancing function, the article suggests that the AR sandbox is a good tool for geoscience education and outreach. The usage of ArUco markers contributes to increased interactivity in the sandbox.
	Time Series for Evaluation of Performance Metrics as of Interaction with an AR-Sandbox Using Brain Computer Interfaces [27].	The research assesses the performance metrics of users who interact with the AR Sandbox via brain computer interfaces (BCI), with the goal of understanding how BCI can improve the user experience and learning outcomes of the AR Sandbox application.	In this research, authors conducted a trend analysis on the time series data collected by measuring performance metrics with the Emotiv EPOC device.	When interacting with immersive environments, the interactivity of students increases due to their interest, engagement, focus, and stress.

Engagement	A novel approach to measuring student engagement using an augmented reality sandbox [30].	The paper presents a novel approach to measure student engagement using AR Sandbox and electrodermal activity (EDA) sensors.	To teach students about earth science fundamentals, the article employs an AR Sandbox with a projection of terrain and a water simulation. The report also employs EDA sensors mounted to students' wrists to assess their involvement with various AR Sandbox treatments.	Using statistical research, the paper discovers that using an AR sandbox boosts student engagement when compared to traditional techniques. The study also discovered that spatial reasoning abilities are favorably connected to EDA levels. According to the article, EDA sensors can be utilized as an objective indicator of student engagement in learning.
	The development of the Game Engagement Questionnaire: A measure of engagement in video game-playing [7].	The Game Engagement Questionnaire (GEQ) is a novel measure of video game engagement developed and validated in this research. The research also investigates the relationship between game participation and cognition, affect, and behavior connected to games.	The GEQ is developed and tested in the article through a series of studies. The paper evaluates the GEQ's psychometric qualities using factor analysis, reliability analysis, and validity analysis. In addition, the research employs experimental and correlational methodologies to investigate the effects of game participation on game-related outcomes.	The GEQ is likewise found to be reliable and legitimate, according to the paper. The study also discovers that game involvement is related to game enjoyment, game preference, game performance, game time, game spending, and game-related outcomes.

	The impact of Mobile Augmented Reality design implementation on user engagement [25].	The study focuses on the impact of the design of AR application on the engagement and interaction of users.	The author uses the AR application prototype to visualize the application design concept and evaluate its impact on human interaction and engagement. The author questioned 200 university freshmen and utilized statistical analysis to gauge their engagement based on their responses.	The paper finds that there is a direct relation between design and user engagement. So, application UI and UX play a vital role in the engagement of users.

Table 1: Comparision table for different literature papers related to Interactivity and Engagement.

3 Methodology

3.1 Research Methodology

To address the central research question of this thesis, the study begins by presenting an overview of AR Sandbox technology implementation and installation. In this context, this study outlines the technical components required for installation and calibration procedures. Following that, the methodology for participant selection and the testing procedures they underwent are examined. Subsequently, the methodology used for questionnaire administration and data collection is explained, providing insights into the test execution process.

Using the AR Sandbox technology, data was collected and analyzed to determine its influence on user engagement and interactivity. A 7-point Likert-Scale questionnaire, along with open-ended questions, was employed for data collection. Data was gathered through a Google form, to which all users responded after testing the AR Sandbox. In addition, demographic questions were included in the form. Subsequently, the collected data was examined using simple descriptive statistics to assess its alignment with our research question and goal.

3.2 Setup and Hardware Components of the AR Sandbox

There are several hardware components involved in building an AR Sandbox. The AR Sandbox comprises various hardware components, including sensors such as the Microsoft Kinect 3D camera, a short-throw projector, and a computer equipped with a high-end graphics card, typically running the Linux operating system. The sand within the sandbox structure serves as the physical medium that interacts with the digital projections generated by these hardware components. A typical setup of AR Sandbox is shown in figure 2. Due to the problem of the position of the projector, we had to mount the projector in different position which can seen in the figure 3. We accomplished the installation of AR Sandbox with the help of UC Davis instructions [1] and with the help of Lake Viz youtube video for calibration [20].

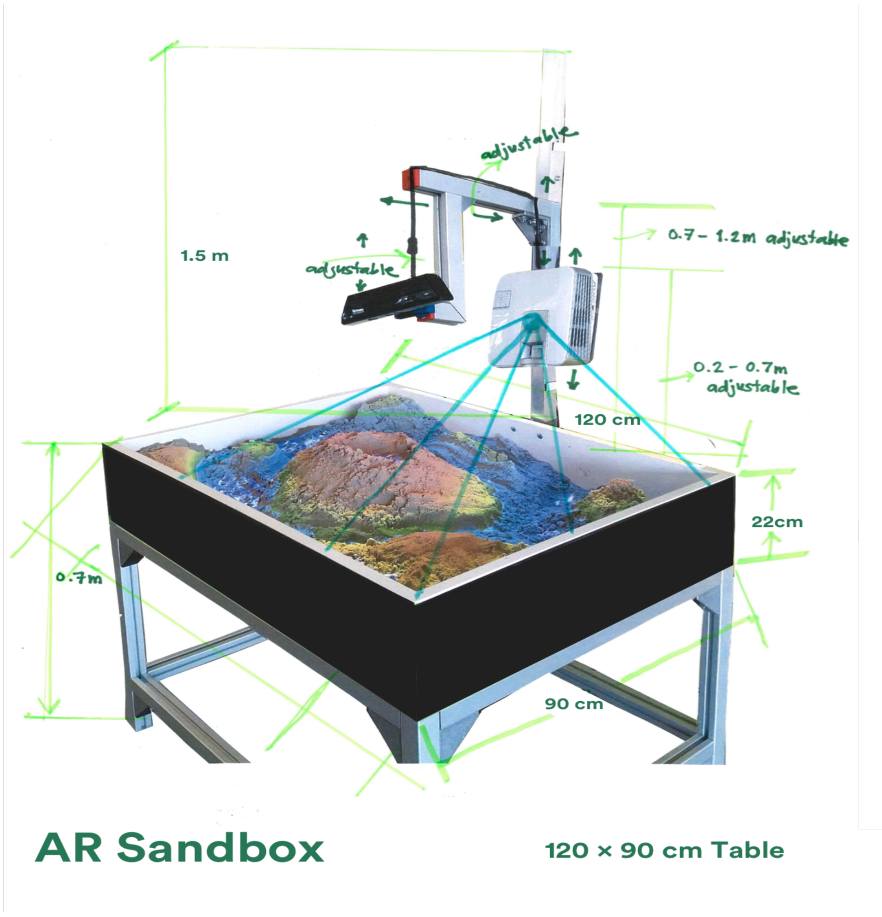


Figure 2: Typical Setup of an AR Sandbox.

In this section, a description of the necessary hardware and software devices, along with other related requirements required for the installation of AR Sandbox, is provided.

1. Kinect Sensor

As a motion-sensing device, the sand surface should be continuously scanned by a unique sort of sensor. We used a second-generation Microsoft 3D camera to scan the sand surface, which typically uses a time-of-flight infrared detection method [33].

2. Projector

The UC Davis setup suggests using a short throw projector with a 4:3 aspect ratio, aligning with the field of view of the Kinect camera [1]. While the initial requirement was for a 4:3 aspect ratio, we chose the Epson projector which was available in a department that has an aspect ratio of 16:10 but this problem can be resolved through the calibration of the projector. Despite the projector having a specific projection angle, we couldn't position it directly above the sandbox. As a workaround, it was situated at the side of the sandbox to ensure complete image projection across the entire area.

3. Sandbox

Through co-operation with the Co-supervisor, we decided the size of the sandbox to be 120cm by 90cm. The height of the sandbox was 22cm which was supported by the strong aluminium frame. As per UC Davis, the requirement is for white kinetic sand. This specific sand variety is optimal for accurately reflecting 3D images compared to its counterparts. However, due to the lack of availability of white play sand in Norway, we opted for regular river sand. While this alternative has slightly diminished projection capabilities compared to white play sand, it still suffices for the projection needs. Moreover, the cost-prohibitive shipping charges from other countries deterred us from choosing white sand.

4. Data Processing

The scanned signal from the sensor was processed by the powerful computer having a high-end Nvidia GeForce Graphics Processing Unit (GPU) running in the Linux operating system. The widely used UC Davis software package (https://web.cs.ucdavis.edu/ okreylos/ResDev/SARndbox/) is commonly used for this purpose available for Linux. We used a 64-bit version of Linux Mint 19.3 as an operating system on the computer.

The sensor driver collects digital data about the height of the sand in the sandbox. This raw data needs to be processed before it can be used. The processed data can be used to create content based on the height of the sand, and this content can be displayed on the sandbox surface by projecting an image onto the sand. It was important to adjust the height of the sand according to the area of interest [33]. Figure 3 depicts the running of the built sandbox with simulated water and assembled projector and sensor.

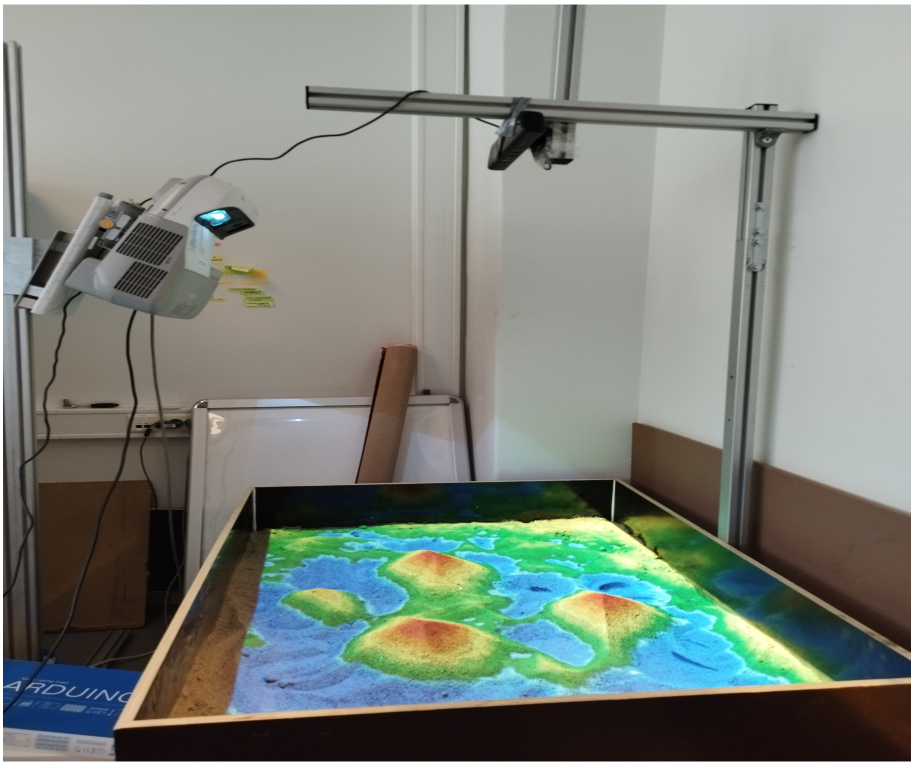


Figure 3: AR Sandbox with water simulation.

3.3 Calibration of AR Sandbox

The process of calibrating an AR sandbox is necessary for ensuring that the data collected by the sensors is accurate. This involves adjusting the sensors and other hardware components so that they can accurately measure the height of the sand. Calibration can also help to improve the performance and accuracy of the AR sandbox overall. It is important to perform calibration in order to produce reliable results when using the sandbox.

After mounting the projector and Kinect, the calibration between the projector display and the camera was performed. This process aligns the Kinect's depth image with the projection on the sandbox surface, enabling the AR Sandbox application to accurately display the topography [24]. According to the instructions provided by UC Davis [23], the calibration was done using a circular disk with a sheet of paper attached to it. A cross was drawn on the paper that intersected at the center of the disk. The disk was then attached to a simple juice can to avoid interference of hand.

This allowed for the calibration to be performed accurately.

The calibration process was initiated by executing the command "./bin/CalibrateProjector -s 1280 800" [23], where the values 1280 and 800 correspond to the projector's image width and height in pixels, respectively. This calibration procedure involves projecting a white cross onto the surface of a sandbox and aligning it with a cross displayed on a disk, as illustrated in figure 4. To establish tie points, observations are made at different elevations, commencing with a flat surface and progressively excavating to the sandbox's lowest point. Subsequently, multiple tie points are recorded at varying heights, enabling the projector to display a red cross that tracks the calibration disk at different positions within the sandbox. In cases where the red cross fails to appear at specific locations, additional tie points are collected to ensure precise calibration. Once the red cross satisfactorily aligns at various positions, the acquired data was stored in a projector transformation file for utilization by the AR Sandbox application [24].

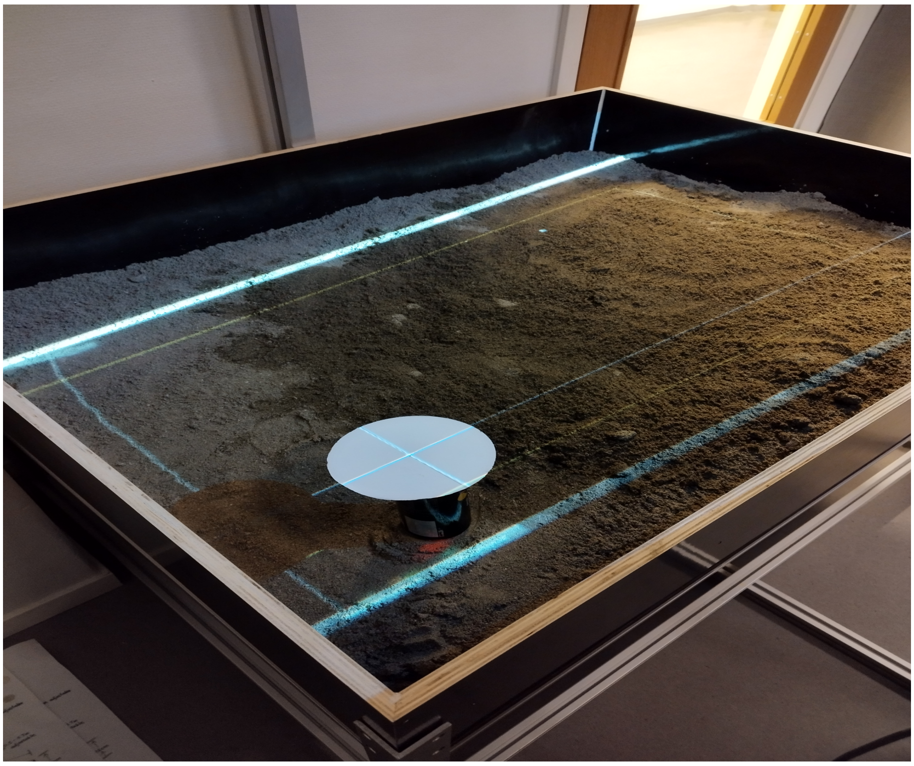


Figure 4: Calibration disk for collection of tie points.

3.4 Running of AR Sandbox

After the completion of calibration and storing the calibrated data, the sandbox framework can be run in the Linux terminal by using the command "./bin/SARndbox -uhm -fpv" [23]. The -uhm argument tells the SARndbox software to apply an elevation color map to the sand surface, and the -fpv argument tells it to use the projector/camera calibration collected. After the execution of the given command, the image showing the topography, contour lines, and elevation on the sand was observed. When we move or manipulate the sand, eventually Kinect detects the changes in elevation and sends it to the PC having SARndbox software [23] due to which the shape of contour lines changes. We tried to make the mountain shapes and some steeped shapes, Kinect also detected the changes in sand elevation and changed the contour lines eventually. Figure 5 shows the image of topography and contour lines running in AR Sandbox software on a PC. The next figure 6 depicts the image of the projection of topography, contour lines, and simulated water onto the sand surface.

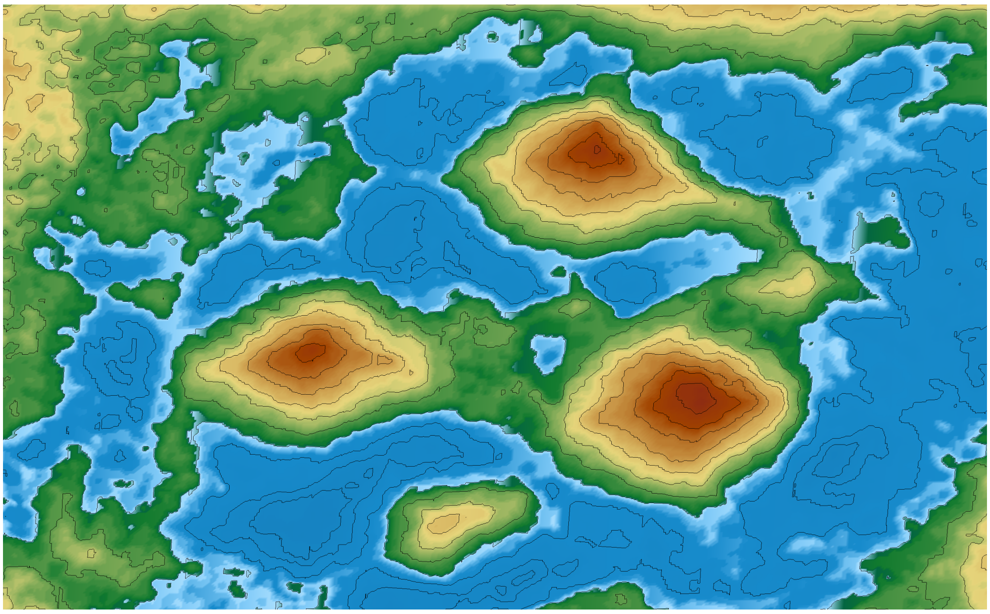


Figure 5: AR Sandbox application running on PC.

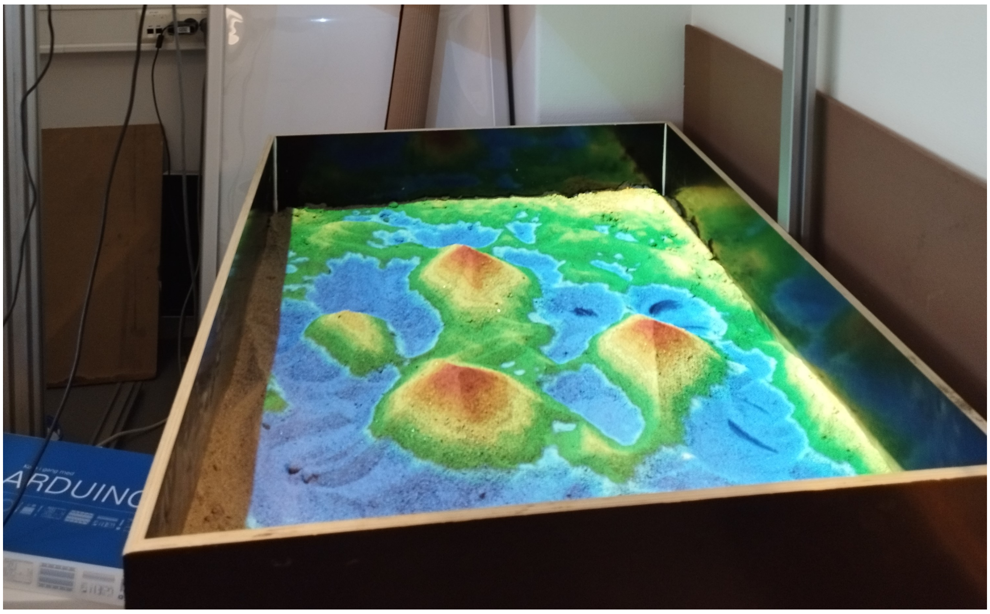


Figure 6: AR Sandbox Projection.

The SARndbox application has a feature that allows users to create simulated water by placing their hand under the sensor. When this is done, the virtual water will flow down from the hand and onto the surface of the sand. This is just one of the many visually appealing features of the SARndbox application which can be an immersive experience for the users when they are testing the system. The simulated water system in an AR Sandbox allows users to see how water would flow over a landscape in real time by simulating its flow in response to changes made by the user. When the user modifies the topography of the sandbox, such as by creating mountains or valleys, the software calculates how water would flow over the new terrain and displays a projection of the water onto the sandbox. The user can observe the water as it flows and shapes the terrain, creating channels and valleys through erosion. We can see the image where the simulated virtual water is flowing through the hands and on the surface of the sand. A water flow simulation is a computer model that uses the Saint-Venant set of shallow water equation 1 to predict how water will behave in a given situation. This equation is simplified version of the Navier-Stokes equations, which are used to describe the behavior of fluids [19], and they are specifically designed for situations where the water depth is small compared to the length and width of the channel or area being considered. By using these equations, a water flow simulation is able to accurately predict the flow of water in shallow channels or overland flow, such as in the case of a river or a flood [26].

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + g\frac{\partial H}{\partial x} - \frac{1}{H}\frac{\partial (u^2 H)}{\partial x} - \frac{1}{H}\frac{\partial (uvH)}{\partial y} = S \tag{1}$$

where, u and v are the velocities of the water in the x-direction (horizontal) and y-direction (vertical), respectively, H is the water depth, x and y are the spatial co-ordinates,t is time, g is the acceleration due to gravity, S is a source or sink term that represents any external forces acting on the water, such as the force of gravity or the resistance of the channel.

3.5 Participant Recruitment and User Tests

The decision was made to invite users to test our AR Sandbox after its implementation. More than 20 individuals were invited with the aim of studying the data collected from them. Because the university is typically closed during the summer, inviting classmates during that period posed a challenge. Consequently, friends from my home country who were in Trondheim were selected as the invitees. The decision was made to extend invitations to them throughout the month of July. The majority of the participants are from various departments at NTNU. Some of the participants are full-time professionals in Trondheim. The decision to schedule participation over the weekend was made due to the availability of most participants during that time. Prior to inviting them, essential preparations were made, including the creation of questionnaires using Google Form, an introductory document, and a consent form. These measures allowed participants to provide prompt responses after engaging with the AR Sandbox. However, prior to commencing the experiment, clearance from the supervisor was required. An email was sent to the supervisor to request permission for the experiment. After a week's time, clearance was received, and the process of inviting individuals began at the end of July. Subsequently, the system underwent one week of testing.

Our objective was to have users test the AR Sandbox and quantify the impact of the technology on their engagement, and interactivity. Given that subjective user tests can be influenced by numerous factors, our approach involved minimizing these potential influences to ensure reliable results.

3.5.1 Data Collection

A Google form was created for data collection that includes demographic information, 7-point Likert-Scale questions, and some open-ended questions. The questions are attached in Section D in the appendix section.

a. Likert-Scale Questionnaires

We developed a comprehensive Likert-Scale questionnaire, carefully designed with 7-point Likert-Scale items to assess user engagement and interactivity. Some of the questions in our Likert-Scale were inspired by the paper *A Multi-Dimensional Model of Enjoyment: Development and Validation of an Enjoyment Scale (Enjoy)* [10]. The Likert-Scale questionnaire included questions related to aspects such as immersion, interaction, interaction duration, and instances of losing track of time. Some of the questions were related to the feedback and features of AR Sandbox.

The questions related to engagement were:

No.	Question/Statement
1	I was fully focused on the content in the AR sandbox.
2	I felt engaged and absorbed in the AR sandbox experience.
3	I lost track of time during the AR sandbox session.
4	I felt a strong sense of immersion in the content in the AR sandbox.
5	I spent more time on the storytelling than I expected.

Those five questions deal with immersion, losing track of time, and storytelling.

The questions related to interactivity were:

No.	Question/Statement
1	The level of interactivity provided by the AR sandbox was satisfying.
2	The AR sandbox system allowed me to manipulate the virtual elements easily.
3	The interactive elements in the AR sandbox were intuitive and easy to understand.
4	I felt a sense of control and agency while interacting with the stories in the AR sandbox.
5	I found the interactive features of the AR sandbox enjoyable.

The last four questions were related to feedback, user experience, and features of AR Sandbox. They were:

No.	Question/Statement
1	The content in the AR sandbox was relevant to my interests and goals.
2	The content in the AR sandbox provided me with useful feedback and guidance.
3	The AR sandbox was reliable and responsive.
4	The AR sandbox had a high-quality visual design.

b. Demographic Information

In addition to the Likert-Scale question, several demographic questions regarding the user's age, gender, educational background, prior experience with AR technology, and knowledge of AR Sandbox were included in the form in Section D.

3.5.2 Tests Execution

A total of 27 participants were invited, primarily coming from NTNU and representing diverse academic disciplines. Additionally, some participants were from outside of NTNU. The tests were carried out at NTNU's Department of Electronic Systems' ULTIMATE lab. The tests were carried out between the end of July and the first week of August. Some individuals tried the system in groups, while others did it alone. They began the experiment by first reading the introduction paper and signing the consent form. The introduction paper and consent form are attached in Section B and Section C respectively. Before initiating the test, some information on the AR Sandbox was also provided. Some participants were familiar with the system but had never used it previously, and others had no idea what it was. Some participants experienced the system for five minutes and some of them explored more than that. After testing the system, they answered the questionnaires. The image of the participant experiencing the AR Sandbox can be seen in the figure 7.

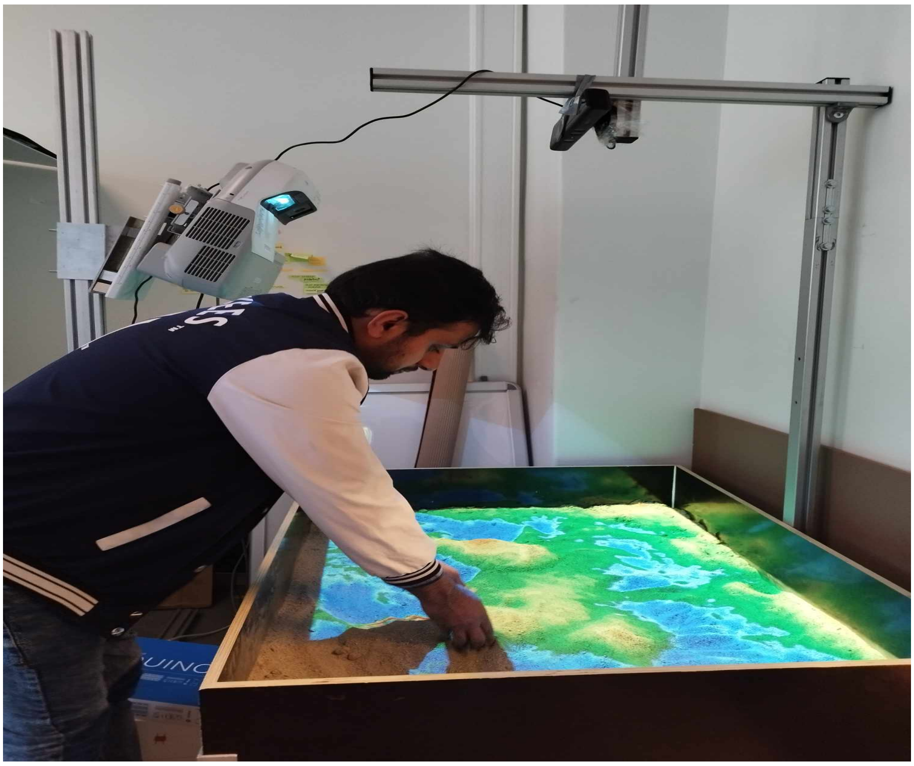
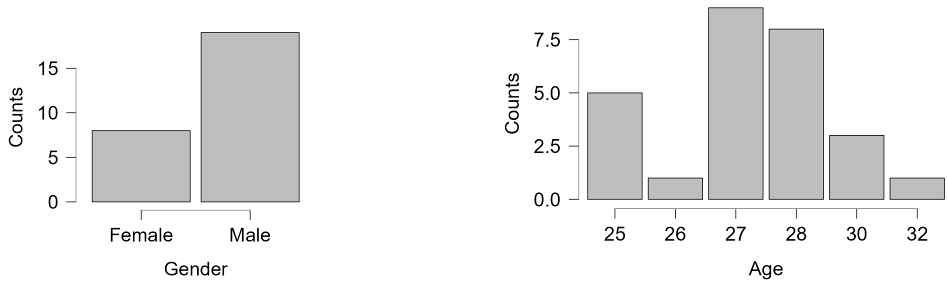


Figure 7: A participant experience the system.

4 Results

4.1 Results from Data

Here the mean, median, and mode for Likert-Scale responses to assess the level of user's interactivity and engagement are calculated. We used JASP (Jeffreys' Amazing Statistics Program), a user-friendly statistical software and SPSS (Statistical Package for the Social Sciences), to calculate the descriptive statistics. The figure 8 depicts the distribution of different genders and ages. We can also observe frequency tables for both gender and age in the given figure 9. All of the participants in the experiment are NTNU students from various departments, with some coming from outside the university.



What is your Gender?

What is your age?

Figure 8: Distribution of Gender and Age.

Frequencies for Gender

Gender	Frequency	Percent	Valid Percent	Cumulative Percent
Female	8	29.630	29.630	29.630
Male	19	70.370	70.370	100.000
Missing	0	0.000		
Total	27	100.000		

Frequencies for Age

Age	Frequency	Percent	Valid Percent	Cumulative Percent
25	5	18.519	18.519	18.519
26	1	3.704	3.704	22.222
27	9	33.333	33.333	55.556
28	8	29.630	29.630	85.185
30	3	11.111	11.111	96.296
32	1	3.704	3.704	100.000
Missing	0	0.000		
Total	27	100.000		

Figure 9: Frequency tables for Gender and Age.

We have 14 Likert-Scale questions to assess the AR Sandbox's interaction and engagement. Five of the fourteen questions were about interaction, five were about engagement, and four were about the features and feedback of AR Sandbox. These 14 questions were designed as a 7-point Likert-Scale, with values ranging from 1 (Strongly Disagree) to 7 (Strongly Agree). Because there is no comparison between the groups, we simply need to look at the basic descriptive statistics for our data.

4.1.1 Descriptive Statistics

Starting with interactivity, we have a total of five questions about it. Initially, we created a composite variable of all those questions by taking an average of all those five questions together and creating a new variable called Total Interactivity. Then using descriptive statistics in SPSS, the mean, median, and mode were calculated. Table 2 depicts the statistical description for Total Interactivity, including mean, median, and mode values. The median value will be used to analyze the data, so they are crucial and also act as the central tendency of data.

	Total Interactivity
Valid(N)	27
Missing(N)	0
Mode	5.600
Median	5.600
Mean	5.415

Table 2: Descriptive Statistics-Total Interactivity.

Also, there were five engagement-related questions on the list. A new variable called Total Engagement was created for this study by averaging the results of all five questions. Using descriptive statistics, the total engagement's mean, median, and modes were calculated which is displayed in the table 3.

	Total Engagement
Valid(N)	27
Missing(N)	0
Mode	5.400
Median	6.00
Mean	5.785

Table 3: Descriptive Statistics-Total Engagement.

Two questions were related to the rating of the level of interactivity and engagement in which users can rate their level of interaction and level of engagement after testing the AR Sandbox. The mean for both level interaction level and engagement level for users were calculated as shown in the table 4.

	InteractionLevel	EngagementLevel
Valid(N)	27	27
Missing(N)	0	0
Mean	7.444	7.407

Table 4: Descriptive Statistics for rating of Interaction Level and Engagement Level.

Two of the questions were related to experience with AR technology and familiarity with AR Sandbox technology. They were: *1. Have you had any prior experience with Augmented Reality (AR) technologies?* and *2. Are you familiar with AR Sandbox or similar systems before?*. We used Yes/No alternatives for those questions. The frequency tables for both questions are shown in table 5 and table 6 respectively, where we can obtain information about the percentage of participants who are familiar with those technologies.

Prior_Ar_Experience	Frequency	Percent	Valid Percent	Cumulative Percent
No	7	25.926	25.926	25.926
Yes	20	74.074	74.074	100.000
Missing	0	0.000		
Total	27	100.000		

Table 5: Frequency table for Prior Ar Experience.

Familiar_with_ARSandbox	Frequency	Percent	Valid Percent	Cumulative Percent
No	22	81.481	81.481	81.481
Yes	5	18.519	18.519	100.000
Missing	0	0.000		
Total	27	100.000		

Table 6: Frequency table for Familiarity with AR Sandbox.

The last two questions were open-ended questions. They were: *1. How did the design and functionality of the AR sandbox influence your experience and your engagement and interactivity levels?* and *2. Do you have any feedback or comments for improving the AR sandbox?* The answers are attached to the Section D.1 and Section D.2 respectively.

4.2 Data analysis

This descriptive study explores the impact of Augmented Reality (AR) Sandbox technology on user interactivity and engagement. The study examines the influence of AR Sandbox on user engagement and interaction levels, identifies potential limitations, and draws connections to related research studies.

4.2.1 Findings

The primary research question addressed in this study is how AR Sandbox technology affects user interactivity. The second research question addressed in this study is how AR Sandbox technology affects user engagement. To investigate those elements, the author utilized a descriptive approach. Data was collected from participants and employed descriptive statistical methods, such as mean and median calculations.

1. Increased Interactivity

The study's findings suggest that the implementation of Ar Sandbox technology has a positive impact on user interactivity. The Likert-Scale median value of 5.6 indicates that the majority of participants perceived a moderate level of interactivity. This demonstrates that the AR Sandbox system enhances user interactivity to some extent.

i. Potential Causes of Low Interactivity

- **Small Sample Size:**

  The study acknowledges the limitation of a small sample size, which restricted the researchers from conducting in-depth analyses like hypothesis testing and data correlation.

- **Lack of Playful Features:**

  The absence of playful features, such as gamification, in the AR Sandbox system is identified as a potential reason for the relatively low level of interactivity.

- **System Limitations:**

  The system design and components, including outdated equipment and the choice of sand, are recognized as factors affecting the quality of user interaction.

ii. Related Research on Interactivity

The study establishes links to three relevant research papers, which will serve as the basis for supporting our findings and methodology. We will examine both the commonalities and differences among these papers to inform our approach related to interactivity.

***a. "Distributed Spatial Sensemaking on the Augmented Reality Sandbox"* [16]:**

This paper focuses on gesture-based interaction and collaborative dynamics facilitated by the AR Sandbox technology. It highlights the AR Sandbox's capacity to engage users actively in shaping virtual terrains in real-time through physical sand manipulation, complemented by gesture-based interaction which is similar to the present study's findings. Both investigations share a common thread in their focus on the dynamic interactions enabled by the AR sandbox, notably placing emphasis on gesture-based engagement. While our research methodology differed, with the use of questionnaires as opposed to interaction analysis, both studies coalesce in highlighting the AR Sandbox's exceptional capacity to foster dynamic user interactions. This convergence reaffirms the profound significance of AR Sandbox technology in a multitude of interactive and educational contexts.

***b. "Open AR Sandbox: A haptic interface for geoscience teaching and outreach"* [33]:**

This research underscores the transformative potential of AR Sandbox technology in geoscientific teaching and outreach. Notably, the methodology used in the research reflects the spirit of our own investigation, demonstrating a common emphasis on developing dynamic and engaging encounters. The mentioned paper used Python-based open-source software to link an AR sandbox system with a 3-D geomodeling platform. Furthermore, the incorporation of ArUco-marker detection emerged as a critical feature, improving the sandbox's precision and flexibility—an aspect that complements our emphasis on gesture-based interaction as a means of increasing user interactivity. These findings are very similar to our own research findings, in which we also saw increased interactivity among individuals when exposed to the AR Sandbox environment. Both studies accentuate the remarkable capacity of AR Sandbox technology to not only visualize complex concepts but also to shape engaging and interactive user experiences, highlighting its versatility and potential as an educational tool for fostering immersive learning.

***c. "Time Series for Evaluation of Performance Metrics as of Interaction with an AR-Sandbox Using Brain Computer Interfaces"* [27]:**

This study looks at augmenting AR Sandbox interaction using brain-computer interfaces (BCI) in order to improve user experiences and learning outcomes. Both, our research and this study are concerned with increased interactivity. According to the study, students who participate in immersive environments exhibit enhanced interactivity as a result of increased attention, engagement, attentiveness, and even tension. This is supported by our research, which emphasizes the AR sandbox's ability to engage people through gesture-based manipulation and dynamic interaction with virtual items. While our methodology is based on questionnaires and theirs is based on time series data collected via the Emotiv EPOC device, both capture the subtle dynamics of user interaction within the AR sandbox environment. This collaboration demonstrates the versatility of AR sandbox capabilities in enhancing user experiences and has the potential for a wide range of educational and interactive applications.

Overall the present study highlights the consistent and positive impact of AR Sandbox technology on user interactivity across various contexts. It acknowledges the potential limitations, such as a small sample size and the absence of playful features, while also emphasizing the system's potential for improvement. The study's findings reinforce the value of AR Sandbox elements as tools for immersive learning and interactive experiences and suggest that further enhancements, including playful features, can increase user interactivity.

2. Increased Engagement

The study's findings indicate that the implementation of AR Sandbox technology significantly boosts user engagement. The Likert-Scale median value of 6.0 demonstrates that the majority of participants perceived a high level of engagement. This suggests that AR Sandbox technology can sustain a high degree of engagement among users.

i. Related Research on Engagement

The study also establishes links to three relevant research papers, which will serve as the basis for supporting our findings and methodology. We will examine both the commonalities and differences among these papers to inform our approach related to engagement.

***a. "A novel approach to measuring student engagement using an augmented reality sandbox"* [30]:**

This study introduces a pioneering method that combines AR Sandbox technology with Electrodermal Activity (EDA) sensors, offering a unique perspective on evaluating student involvement. The findings from this paper resonate with our own observations, revealing that the incorporation of an AR Sandbox significantly amplifies student engagement compared to traditional teaching methods. Moreover, the research uncovers a positive correlation between spatial thinking ability and EDA levels, suggesting that EDA sensors can serve as an objective metric for assessing student participation during the learning process. In tandem with these insights, our study delves deeper into the immersive qualities of the AR sandbox environment, user interaction duration, and instances where participants reported losing track of time. Collectively, these findings underscore the critical importance of AR sandbox technology in augmenting student engagement, underscoring its adaptability and potential to foster immersive and participatory learning experiences across a broad spectrum of educational domains.

***b. "The Development of the Game Engagement Questionnaire: A Measure of Engagement in Video Game-Playing"* [7]:**

This groundbreaking study introduces the GEQ(Game Engagement Questionnaire), a revolutionary measure meant to quantify video game participation. While our interests differ from video games, we both have a similar interest in understanding the aspects that influence participation in engaging settings. We investigated the impact of AR Sandbox technology on user engagement using several indicators such as immersion levels, interaction duration, and occasions when participants lost track of time in our study with the help of responses from users through the questionnaires. Furthermore, both studies investigate the relationship between technology use and various outcomes, with the GEQ investigating aspects of enjoyment, preference, performance, time spent, and expenditures in the context of video games, and our research investigating educational applications of AR sandbox technology in fostering user engagement. Despite the differences in interactive contexts, both research emphasize the importance of technology in shaping engagement experiences, indicating a broader interest in understanding and improving user experiences inside interactive environments.

***c. "The impact of Mobile Augmented Reality design implementation on user engagement"* [25]:**

This study investigates the impact of AR application design on user engagement. While our study focuses on a specific AR technology in the form of an augmented reality sandbox, both studies share a core interest in understanding how design decisions influence user engagement and interaction. In our case, we investigated the educational applications of augmented reality sandbox technology, analyzing user involvement by measures such as immersion, interaction duration, and times when participants reported losing track of time. The research [25], on the other hand, uses statistical analysis and user reactions to examine the design of AR applications and their impact on user engagement. Regardless of the many AR technologies used, the central issue stays consistent: the critical role of design in determining user engagement. Both studies emphasize that, whether in educational settings or application design, deliberate design decisions have a significant impact on user engagement, underlining the universal importance of user-centered design principles in immersive technology interactions.

Overall, the present study reveals that AR Sandbox technology has a positive and significant impact on user engagement. It emphasizes the importance of design choices and technology in influencing engagement, which is consistent across educational settings, video games, and mobile applications. This highlighted detailed perspective shows the versatility of immersive technology and its potential to enhance engagement across various domains.

5 Discussions

In this section, we explore deeper into the implications of our findings regarding the impact of Augmented Reality (AR) Sandbox technology on user experiences. Building on the data analysis reported previously, we now investigate the impact of AR Sandbox on user interactivity and engagement. This discussion tries to offer insight into the multidimensional nature of these features in the context of AR technology. In addition, we investigate potential constraints and make connections to relevant research papers that support our findings. By participating in this discussion, we acquire a better grasp of how AR Sandbox technology might alter user interaction and engagement.

5.1 Impact on User Interactivity

In line with our primary research question regarding the influence of AR Sandbox technology on user interactivity, this study's findings suggest that the technology has a moderate level of interactivity. However, it is critical to recognize any limitations that may have influenced these findings. First, the paper acknowledges the study's sample size limitation, which limited the depth of our analyses, including hypothesis testing and data correlation. Second, the lack of playful features in the AR Sandbox system is suggested as a possible explanation for the comparatively low level of interactivity seen. Third, system design and components, such as old equipment and sand selection, were identified as factors influencing user interaction quality.

We dived into three research publications, as noted in the findings section, that shed light on the effects of Augmented Reality (AR) Sandbox technology on user interactivity in the context of our study. These publications have repeatedly emphasized the AR Sandbox's unique capacity for dynamic interaction, underlining its critical role in encouraging active user participation and shaping immersive virtual experiences. While each of these research used different methodologies and circumstances, their aggregate resonance with our findings confirms the idea that AR Sandbox technology consistently and positively improves user interaction in a variety of scenarios.

Finally, the combination of our research findings and other studies indicates the compelling and consistent influence of AR Sandbox technology on user interaction in a range of scenarios. These findings emphasize the versatility and revolutionary potential of AR sandbox features in improving user interaction and involvement, highlighting their worth as valuable tools for immersive learning and interactive experiences. However, there is room for improvement of the system with the help of playful features to increase the interactivity of users.

5.2 Impact on User Engagement

Turning to our second research question regarding the influence of AR Sandbox technology on user engagement, this study's findings suggest that the technology has a higher degree of engagement of users than that of influence in interactivity. There could be several factors for high engagement such as higher immersion level among the users, loss of track of time while playing with the system, and so on.

As mentioned in the findings section, we delved into three research publications that shed light on the effects of Augmented Reality (AR) Sandbox technology on user engagement in the context of our study. These studies, taken together, highlight the dynamic nature of user involvement in engaging environments, as well as the importance of understanding the factors that drive participation in engaging settings. While each experiment looked into a different aspect of user engagement, they all point to the transformative potential of AR Sandbox technology in improving user engagement across a range of educational and interactive applications. This common theme emphasizes the importance of design decisions and technological advancements in affecting user engagement and indicates possible future research and development options in this dynamic industry.

Our engagement discussion synthesizes findings from previous studies as well as our own research on augmented reality sandbox technology. These studies highlight the critical importance of design choices and technology in affecting user engagement. The general value of deliberate design concepts in captivation and absorption is seen in educational situations, video games, and mobile applications. The unifying concept of improving user experiences via design is consistent across varied user populations and immersive technology. This comprehensive viewpoint emphasizes the versatility of immersive technology and its potential to stimulate participation across a wide range of areas.

In conclusion, our research demonstrates the favorable impact of Augmented Reality (AR) Sandbox technology on user interaction and engagement. While our findings indicate a modest amount of interactivity, some limitations such as sample size and the absence of entertaining aspects have been recognized. However, our findings are consistent with previous research, indicating the consistent potential of AR Sandbox technology to improve user interaction across a variety of scenarios. Furthermore, our research into user engagement reveals a higher degree of engagement, which can be linked to aspects such as improved immersion and user absorption in the AR Sandbox. Finally, AR Sandbox technology shows potential for producing immersive and engaging experiences, with space for growth through smart design changes.

6 Conclusion

This study has undertaken an exploration to comprehend the impact of AR technology, by using an AR Sandbox on user interactivity and engagement. The combination of rigorous research methodologies, a detailed literature review, and data analysis has provided us with significant insights into the dynamics of AR technology and its impact on user experiences. Our research began with the implementation and installation of AR Sandbox technology, demonstrating the technical complexities that drive this immersive tool. We laid the groundwork for a user-centric inquiry through calibration and setup. Following participant recruitment and testing, our methods enabled us to see firsthand the transforming potential of the AR Sandbox. Our participants' experiences and interactions revealed the potential for augmented reality to take interactivity and engagement to new heights. The interaction between physical manipulation and digital augmentation created an environment in which users could modify their virtual landscapes, regulate water flow, and interact with topographic concepts in ways that went beyond typical learning paradigms. Our data analysis, relying on descriptive statistics, indicated that AR technology indeed exerted an impact on user interactivity and engagement. However, the absence of certain playful and additional elements, partly stemming from user feedback, constrained interactivity from reaching their full potential. It's also important to note that the modest sample size may have influenced these outcomes, and the absence of hypothesis testing limits the strength of these findings. In addition, our research delved into a broader exploration of literature, where we rigorously matched our findings to the insights acquired from numerous studies. The similarities and differences we discovered highlighted the varied nature of AR technology's influence on engagement and interactivity. AR technology has shown itself to be a versatile tool with applications in a wide range of fields, from user-brand engagement to user-user interactions and bystander engagement.

In conclusion, our findings underscore the exciting possibilities of AR Sandbox technology in enhancing user engagement and interactivity. It opens promising avenues in education, outreach, and beyond, where immersive learning experiences could reshape how we engage with information and ideas. While our implementation didn't fully maximize interactivity and engagement, mainly due to the absence of playful features identified through user feedback, it still had a notable impact on these aspects to some extent.

7 Limitations and Future Work

1. Limitations:

This research has contributed insights into the impact of Augmented Reality (AR) Sandbox technology on user interactivity and engagement. However, it is important to acknowledge some limitations that should be considered when interpreting the findings. Firstly, the study's sample size was small, limiting the depth of key analyses such as some hypothesis testing. While the findings indicate significant trends, they may not be fully representative of larger populations. Secondly, the lack of playful elements in the AR Sandbox system may be viewed as a drawback. Gamification, for example, has the ability to greatly increase user experiences. Their absence may have contributed to the study's moderate levels of interactivity. Thirdly, aspects related to system design and components such as the usage of older equipment and sand, may have influenced the quality of user interaction. These elements could have influenced the overall user experience. Finally, while great attention was taken in constructing the questionnaires used for data collection, it is critical to recognize the possibility of questionnaire design biases. The wording of questions or response alternatives may have generated inadvertent biases that influenced participants' responses. These limitations, while taken into account during the study's execution, highlight the need for caution when generalizing the findings and indicate areas for further research and system enhancement.

2. Future Work and Recommendations:

There are various areas for future research and system development based on the findings of this study. Larger-scale research with more varied participants and updated questionnaires could be done to address the limitations associated with sample size and questionnaire design biases. Furthermore, the incorporation of entertaining features, such as gamification tactics, into the AR Sandbox system should be investigated in order to increase user interactivity and engagement. Future research may also focus on optimizing system design and components to improve overall user experience. Researchers and AR technology developers working together could result in more immersive and engaging AR Sandbox systems. Furthermore, looking into the possible instructional applications of AR Sandbox technology in subjects other than geology, such as physics or history, is a fascinating route for future research. This investigation could lead to the creation of customized AR learning environments that address certain educational goals. In conclusion, future efforts should focus on improving AR Sandbox technology, broadening its applications, and performing more extensive studies to gain a better understanding of its impact on user interactivity and engagement across multiple disciplines.

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Appendix

A Software Implementation and Calibration

In this section, all the necessary commands in Linux for the installation of software and commands used for calibration are provided. The necessary command and steps were taken from the UC Davis software installation instructions [23]. The description of each command is described in the same instructions page [23].

The following software are used in this project:

1. Linux Mint 19.3 ("Tricia") with MATE desktop environment, 64-bit version
2. Version 8.0-002 of the Vrui VR Development Toolkit (automatically selected by Vrui installation script)
3. Version 3.10 of the Kinect 3D Video Package
4. Version 2.8 of the Augmented Reality Sandbox

A.1 Software Installation

All the given commands are done in Linux terminal.
Step 1: Install Nvidia Driver in Linux
glxinfo — grep vendor

Step 2: Install the Vrui VR Development Toolkit
cd
wget http://web.cs.ucdavis.edu/ okreylos/ResDev/Vrui/Build-Ubuntu.sh
bash Build-Ubuntu.sh

Step 3 : Install the Kinect 3D Video Package
cd /src
wget http://web.cs.ucdavis.edu/ okreylos/ResDev/Kinect/Kinect-3.10.tar.gz
tar xfz Kinect-3.10.tar.gz
cd Kinect-3.10
make
sudo make install
sudo make installudevrules
ls /usr/local/bin

Step 4: Install the Augmented Reality Sandbox
cd /src
wget http://web.cs.ucdavis.edu/ okreylos/ResDev/SARndbox/SARndbox-2.8.tar.gz
tar xfz SARndbox-2.8.tar.gz
cd SARndbox-2.8
make
ls ./bin

A.2 System Integration, Configuration, and Calibration

Step 5: Connect and Configure the 3D Camera
sudo /usr/local/bin/KinectUtil getCalib 0

Step 6: Align the 3D Camera
cd /src/SARndbox-2.8
RawKinectViewer -compress 0

Step 7: Measure Sandbox's Base Plane Equation
cd /src/SARndbox-2.8
xed etc/SARndbox-2.8/BoxLayout.txt &

Step 8: Measure Sandbox's 3D Box Corner Positions

(-0.0151, 0.0032, 0.9998), -95.2385
(-48.9605, -36.6347, -92.1170)
(48.4700, -37.2360, -90.7238)
(-49.4806, 36.7418, -93.3752)
(46.6865, 35.1888, -89.7917)

The first line of given data represents camera space plane equation data and the remaining other data represents the sandbox's 3D box corner positions. These data should be placed inside the AR Sandbox directory in the name of *BoxLayout.txt*.

Step 9: Align the Projector
XBackground

Step 10: Projector/Camera Calibration
cd /src/SARndbox-2.8
./bin/CalibrateProjector -s <width> <height> ,

where, width and height are our projector's image in pixels, respectively.

A.3 Running the Augmented Reality Sandbox

Step 11: Run the AR Sandbox
cd /src/SARndbox-2.8
./bin/SARndbox -uhm -fpv
where, The $-uhm$ argument tells the SARndbox application to apply an elevation color map to the sand surface, and the $-fpv$ argument tells it to use the projector/camera calibration.

There are also several steps to make a fine AR Sandbox installation which can be found on the UC Davis software installation page [23].

B Introduction Text

NTNU
Norwegian University of Science and Technology

Augmented Reality Sandbox

Dear participant,

Thank you for your valuable participation in this experiment. The study is expected to take approximately 5 to 10 minutes of your time.
In this experiment, you will have the opportunity to experience an Augmented Reality (AR) Sandbox. The AR Sandbox is an interactive and dynamic 3D tool that overlays virtual information onto a real physical environment, such as sand. It has been widely used in scientific and educational contexts due to its intuitive and interactive nature.

The experiment is divided into four main parts:

- **Consent form:** Before proceeding, please sign the consent form provided.
- **Sandbox interaction:** You will have the chance to manipulate and play with the sand in the AR Sandbox. As you manipulate the sand, you will observe different colors and contour lines forming. Please be cautious of the wires connected to the projector and computer, as they could disrupt the experiment.
- **Questionnaire:** Following your interaction with the AR Sandbox, you will be given a questionnaire to complete. The questionnaire will begin with some simple demographic questions, followed by a set of questions related to your reactions and experiences with the system. Please answer the questions truthfully, and don't hesitate to ask the experimenter for clarification if any questions seem unclear or challenging.
- **Data confidentiality**: All data collected during this experiment will be pseudonymized to ensure confidentiality and anonymity.

Please note **that you are not being tested**; rather, **you are testing the system**!

You have the right to withdraw from the study at any point without providing a reason. If you have any questions or concerns during the experiment, feel free to ask the experimenter for assistance.

Now, let's proceed and enjoy the experiment! Thank you once again for your participation.

Experimenter: Hari Bhusal
Tlf: +47 96715852
Email: harib@stud.ntnu.no

C Consent Form

NTNU
Norwegian University of Science and Technology

Consent form

I have read the information for the study of AR Sandbox master's project. I will participate in this study. I was informed that the following data will be obtained today during this study from me: questionnaire with some set of questions and some basic demographic questions. I approve that all recorded data will be saved and will be used pseudomized (e.g. identification data will stored separately from recorded data and only be accessible to a small circle of authorized personnel) for research analysis. All data I give will be handled confidentially. All information will be used for research purposes only. Personal data will not be given to any third party.

I am aware that participating in this study is voluntary and I can withdraw anytime without giving any reason. Doing so I will not suffer in any disadvantage.

Additionally, I am aware that I will handle everything confidentially, I hear and see today, and I will not give any information to other people.

Name: ____

Date: ____

Signature: ____

Experimenter: Hari Bhusal
Tlf: +47 96715852
Email: harib@stud.ntnu.no

D Questionnaire

AR Sandbox Questionnaire

This is a survey created to collect data from the users tests. Please answer truthfully.

* Indicates required question

1. 1. What is your age? *

2. 2. What is your Gender? *

   Check all that apply.

   - [ ] Male
   - [ ] Female
   - [ ] Other
   - [ ] Prefer not to say

3. 3. What is your current occupation or profession?

4. 4. Have you had any prior experience with Augmented Reality (AR) technologies? *

   Mark only one oval.

   - ( ) Yes
   - ( ) No

5. 5. Are you familiar with AR Sandbox or similar systems before? *

   Mark only one oval.

   - ( ) Yes
   - ( ) No

6. 6.Please rate the following statements on a scale from “Strongly Disagree” to “Strongly Agree”. *

Mark only one oval per row.

	Strongly disgree	Disagree	Somewhat disagree	Neither agree nor disagreee	Somewhat agree	Agree	Strong agree
I was fully focused on the content in the AR sandbox.	⬭	⬭	⬭	⬭	⬭	⬭	⬭
I felt engaged and absorbed in the AR sandbox experience.	⬭	⬭	⬭	⬭	⬭	⬭	⬭
I lost track of time during the AR sandbox session.	⬭	⬭	⬭	⬭	⬭	⬭	⬭
I felt a strong sense of immersion in the content in the AR sandbox.	⬭	⬭	⬭	⬭	⬭	⬭	⬭
The level of interactivity provided by the AR sandbox was satisfying.	⬭	⬭	⬭	⬭	⬭	⬭	⬭
The AR sandbox system allowed me to manipulate	⬭	⬭	⬭	⬭	⬭	⬭	⬭

the virtual elements easily.							
The interactive elements in the AR sandbox were intuitive and easy to understand.	◯	◯	◯	◯	◯	◯	◯
I felt a sense of control and agency while interacting with the stories in the AR sandbox.	◯	◯	◯	◯	◯	◯	◯
I found the interactive features of the AR sandbox enjoyable	◯	◯	◯	◯	◯	◯	◯
I spent more time on the storytelling than I expected.	◯	◯	◯	◯	◯	◯	◯
The content in the AR sandbox was relevant to my interests and goals.	◯	◯	◯	◯	◯	◯	◯
The content in the AR sandbox	◯	◯	◯	◯	◯	◯	◯

provided me with useful feedback and guidance.							
The AR sandbox was reliable and responsive.							
The AR sandbox had a high-quality visual design.							

7. 7. In overall, How would you rate your level of engagement with the activity you evaluated? A higher number indicating higher engagement. *

Mark only one oval.

	Engagement
1	◯
2	◯
3	◯
4	◯
5	◯
6	◯
7	◯
8	◯
9	◯
10	◯

8. 8. In overall, How would you rate your level of interaction with the activity you evaluated? A higher number indicating higher interaction. *

Mark only one oval.

	Interaction
1	⬭
2	⬭
3	⬭
4	⬭
5	⬭
6	⬭
7	⬭
8	⬭
9	⬭
10	⬭

9. 9. How did the design and functionality of the AR sandbox influence your experience and your engagement and interactivity levels? Please explain your answer.

10. 10. Do you have any feedback or comments for improving the AR sandbox?

D.1 Experience question

The AR Sandbox helps me to know the AR in an easy way and the sandbox makes me engaged in AR Content.
The AR Sandbox helps me to understand the AR technology in a good way and it helps me in terms of engagement and interactivity.
I don't know more about AR Sandbox but this system helps me to understand AR technology more easily.
I only saw the concept of contour lines, topography, etc. on a 2D map, but this AR Sandbox helps me to visualize these features in a 3D, and AR technology is good to experience.
I think the design and functionality of the AR sandbox were very impressive and engaging. I liked how I could create different scenarios and see how they affect the landscape and the water flow. I felt like I was playing with a real sandbox.
The AR sandbox was a fun and interactive experience. I enjoyed manipulating the sand and seeing the changes in the colors and the contours. The functionality of the AR sandbox was easy to use and understand. I felt more engaged and interested in learning about AR technology.
The AR sandbox was a great learning tool. I liked how I could experiment with different shapes and forms of sand and see how they affect the elevation and the water flow. The design and functionality of the AR sandbox was very intuitive and responsive. I felt more curious and involved in exploring the AR sandbox.
The AR sandbox was an amazing experience. I loved how I could create my own stories and scenarios with the sand and see how they come to life with the colors and the water flow. The design and functionality of the AR sandbox was very creative and innovative. I felt more inspired and entertained by the AR sandbox.
The design and functionality of the AR sandbox were not very appealing or engaging to me. I did not like how I had to use my hands to move the sand and see the effects. I did not feel much connection or immersion with the AR sandbox due to my lack of knowledge about this system.
The AR sandbox was a wonderful experience. I liked how I could collaborate and communicate with others while playing with the sand and seeing the effects. The design and functionality of the AR sandbox were very social and cooperative. I felt more connected and engaged with others through the AR sandbox.
The AR sandbox was a captivating experience. I liked how I could express myself creatively while playing with the sand and seeing the effects. The design and functionality of the AR sandbox was very artistic and aesthetic. I felt more satisfied and delighted by the AR sandbox.
The AR sandbox was a stimulating experience. I liked how I could challenge myself cognitively while playing with the sand and seeing the effects. The design and functionality of the AR sandbox was very logical and analytical. I felt more confident and motivated by the AR sandbox.
After testing this AR Sandbox I got a chance to see AR technology in a better way. This system also enhances my interaction levels.
I saw this type of system on YouTube but didn't get a chance to see it live. So playing with the AR sandbox really enhanced my AR knowledge and got to know how AR can be interactive and immersive.
The design and functionality of the AR sandbox was very engaging and interactive for me. I liked how I had to share the sandbox with others and see their effects. The functionality of the AR sandbox was individualized or personalized. I felt interested in the AR sandbox.
I didn't know much more about this AR Sandbox before but after testing this system, I got some knowledge on AR technology. I also knew that AR can enhance interaction and engagement levels.
After playing with the sandbox, I got a chance to see AR in a better way.
I only got a chance to see and read contour lines and topography in 2D but testing and playing with the sandbox made me more understanding about the contour lines and topography in 3D form. So, I think using such AR technology can enhance interaction and engagement levels.

The design and functionality of the AR sandbox was very immersive and engaging. I felt like I was part of the story and could influence the outcome with my actions. The functionality of the AR sandbox was very user-friendly and interactive. I felt more excited and involved in the AR sandbox.
The AR sandbox was an amazing experience. I liked how I could learn new things about topography and hydrology while playing with the sandbox and seeing the effects. The design and functionality of the AR sandbox was very educational and informative. I felt more knowledgeable and interested in the AR sandbox.
The design and functionality of the AR sandbox were not very influential or engaging for me because I am not very familiar with AR but this system is good for people like me who want to see and test AR in a better way.
The design and functionality of the AR sandbox were very engaging for me because I got a chance to look at AR in a better way. I also like the features like changes in elevation, contour lines, and simulated water make me more immersive in the system.
The AR sandbox was a memorable and unique experience. I liked how I could explore different possibilities and scenarios with the sandbox and create my own stories. The design and functionality of the AR sandbox was very original and innovative. I felt more curious and creative by the AR sandbox.
The AR sandbox was a rewarding and enjoyable experience. I liked how I could see the results of my actions in the sandbox.
The AR sandbox was a fun and interactive experience. I liked how I could collaborate and communicate with others while playing with the sandbox and seeing the effects.
The design and functionality of the AR sandbox were very social and cooperative. I felt more connected and engaged by the AR sandbox due to its haptic and unique features like simulated water and changes in elevation and contour lines.
I really like the technology used in the AR sandbox and this system makes me more engaged in the system and makes it easy to understand AR in a good way.

Table 7: How did the design and functionality of the AR sandbox influence your experience and your engagement and interactivity levels? Please explain your answer.

D.2 Feedback question

It will be nice to have some more features related to the game and other interactive features.
The concept of AR Sandbox is good but it could be more effective if there are some other virtual elements to play.
I think the projector could be mounted at the top of the sandbox and the sand should be white to produce good projection.
I think adding a game in AR Sandbox would be nice to make this system more interactive and engaging.
The setup was messy so mounting the projector in a good position and arranging wires could be done better.
Adding more gamification and other immersive features could be interesting.
I don't know much about this system so I think it's good.
I think adding new devices would make this system better.
I don't know much about it but I think replacing normal sand with white sand would be good.
Replacing the old projector with a new light projector and mounting it in a good position would improve the AR Sandbox better.
I don't have any comments.
I think white sand is more good than normal river sand and the projector should be in a good position so that it could project entirely the sandbox.
I don't have any feedback.
I think replacing the old heavy projector and Kinect with a new one will enhance the effectiveness of the AR sandbox.
Can we add mobile AR to this system? If so it could be interesting for the extra features for the AR sandbox.
No comments.
Sand is too dirty so I think putting good sand is needed to improve this sandbox.
The projector should be placed in the right position and more features could be added to make AR sandbox more effective. But the virtual simulated water using hands is really interesting.
No more comments.
Sand is not so good to play so I think it would be great to put other sand that is free from dust.
Sand is not so good to play. So putting good sand could make the system better for projection.
No such comments. Overall, I really like the system.
Overall, I really like the system. However, adding new technology and devices could make the system better. Adding some playful features to the sandbox would also make users more engaged in the system.
No comments.
No.
I like the system but the setup was messy due to the position of the projector and wires so fixing those can improve the sandbox.
There are no such comments to improve but can we add VR technology to this AR sandbox like VR glasses?

Table 8: Do you have any feedback or comments for improving the AR sandbox?

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Science and Technology