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Chair for Electromagnetic Compatibility

Bachelor Thesis

Investigating the Impact of Environmental Detail Levels on Learning in Virtual Reality for Physics Education using the Millikan Oil-Drop-Experiment

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Abstract

This thesis investigates how varying levels of visual detail in virtual reality (VR) learning environments influence user experience and learning outcomes in the context of the Millikan oil-drop experiment. Three versions of the same simulation were developed using Blender and Unity, differing only in environmental detail: a low-detail minimal room, a medium-detail classroom and a high-detail laboratory. A user study with 30 engineering students evaluated learning performance, perceived workload, user experience, sense of presence, and perceived environment quality using standardized instruments (NASA-TLX, UEQ, and IPQ), the custom-designed VR Environment Questionnaire and pre- and post-knowledge tests. Results showed that all environments significantly improved participants' conceptual understanding of the experiment. The medium-detail environment achieved the highest learning gains and lowest workload, suggesting that moderate realism provides an optimal balance between clarity and engagement. Higher detail increased immersion and enjoyment but also slightly raised perceived workload without improving learning outcomes. These findings highlight that in educational VR, cognitive efficiency depends more on purposeful visual design than on maximum realism, offering practical implications for the development of future virtual laboratory environments.

OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG | EIT | FAKULTÄT FÜR ELEKTROTECHNIK UND INFORMATIONSTECHNIK

Aufgabenstellung für eine Bachelorarbeit

Majed Alnaser

Matrikelnummer: 235153

Thema

Investigating the Impact of Environmental Detail Levels on Learning in Virtual Reality for Physics Education using the Millikan Oil-Drop-Experiment

Aufgabenstellung

Virtual Reality (VR) offers new opportunities for immersive and interactive learning experiences. In science education, and particularly in physics, VR can help visualize abstract experiments and enhance user engagement. This thesis focuses on the design, implementation and evaluation of a VR-based simulation of the Millikan oil-drop experiment. The core objective is to investigate how different levels of visual detail in the surrounding virtual environment influence user experience and learning outcomes.

The simulation will be developed using Blender for 3D modeling and Unity for interaction logic and VR integration. The same experimental setup will be embedded into three separate environments of increasing complexity (low, medium and high detail), allowing a structured comparison between minimalist and highly immersive settings. The final stage of the thesis involves conducting a user study with participants who will experience the VR environments and complete a short survey or questionnaire. The collected data will be used to answer the research question:

"How does the level of visual detail in a VR learning environment affect user experience and learning outcomes when simulating the Millikan oil-drop experiment?"

This investigation of level-of-detail in VR learning environments is not limited to physics experiments; it is likewise applicable to medical technology and engineering education, where complex experiments can also be delivered in VR for educational purposes.

Tasks in Detail:

1. Literature Review
   - Review existing applications of VR in science and physics education
   - Study psychological foundations on visual complexity, cognitive load and immersion in VR
   - Explore evaluation methods for VR learning environments

2. Concept and Design
   - Model the Millikan oil-drop experiment and related animations in Blender
   - Design three distinct virtual environments: low-detail, medium-detail and high-detail
   - Define the visual characteristics and educational purpose of each environment

3. Implementation
   - Import models and animations into Unity
   - Implement basic user interactions (e.g., pressing a sprayer)
   - Integrate VR functionality using suitable Unity XR tools

4. Evaluation
   - Design and conduct a user study with participants experiencing all three environments
   - Prepare and apply a survey or questionnaire to measure user experience and learning outcomes
   - Analyze the results to answer the research question

5. Documentation
   - Write a structured thesis based on the research, design, implementation and evaluation
   - Discuss the results and reflect on design choices and possible future improvements

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Magdeburg, 01.09.2025

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Declaration by the candidate

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Magdeburg, October 29, 2025

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1 Introduction

1.1 Motivation

Understanding complex experiments in physics often requires more than theoretical explanations. Many setups involve abstract concepts or complex equipment that students struggle to visualize through textbooks or lectures alone. A prime example is the Millikan oil-drop experiment, a fundamental part of physics education, yet difficult for learners to comprehend intuitively.

Virtual reality (VR) offers a promising solution by providing immersive and interactive simulations that allow students to engage with experiments in a first-person perspective. By enabling active participation and spatial exploration, VR can help make abstract content more accessible, enhance understanding and increase learner motivation. These advantages make VR an increasingly attractive tool for educational settings [1, 2].

However, the surrounding virtual environment itself can significantly influence the effectiveness of learning. The level of visual detail (such as the presence of posters, furniture, objects, distractions or even subtle animations) affects how focused, immersed or distracted users feel [3]. While realistic environments may strengthen engagement and presence, they may also raise cognitive load and divert attention from the actual learning objectives. This issue is not limited to virtual environments. In traditional classrooms and laboratories, distractions such as background noise, visual clutter or unnecessary materials can also impact learning. Therefore, the question is not simply whether detail enhances realism or well-being, but whether detail supports learning, and at what point it becomes too distracting [3, 4].

While prior studies have explored interactivity and instructional design in VR, the role of environmental complexity has received considerably less attention [5]. This is especially relevant in scientific learning scenarios, where cognitive demands are already high and overloaded visual settings may hinder rather than enhance learning outcomes [4].

This thesis is motivated by the need to better understand how different levels of environmental detail in VR affect both user experience and learning performance, especially in the simulation of abstract scientific experiments.

1.2 Aim of the Thesis

This thesis aims to answer the question: How does the level of visual detail in a VR learning environment affect user experience and learning outcomes when simulating the Millikan oil-drop experiment? To explore this, a VR simulation of the experiment will be created and placed into three different environments:

- A low-detail space with minimal distractions.
- A medium-detail classroom setting.
- A high-detail laboratory filled with visual objects.

User testing will be conducted to evaluate how each environment influences cognitive load, sense of presence, user experience and comprehension of the experiment. These dimensions will be measured using standardized questionnaires and a structured knowledge quiz.

It is important to note that this study focuses exclusively on **visual distractions** to isolate their effects on learning and user experience. Other potential sources of distraction (such as background noise, sound effects or the presence of virtual characters) are deliberately excluded from this investigation. Addressing these additional sensory and social factors would be an interesting direction for future research, as combining multiple types of distractions could make it more difficult to identify the specific impact of visual complexity alone.

1.3 Structure of the Work

This thesis is structured as follows:

Chapter 2: *Background and Related Work*
Provides the theoretical foundations and relevant prior research. It introduces the Millikan oil-drop experiment, virtual reality concepts, applications of VR in physics education and insights from learning psychology related to visual detail.

Chapter 3: *VR Environment and Experiment Design*
Describes the design of the experiment and the concept behind three virtual environments with varying levels of detail: low, medium and high.

Chapter 4: *Implementation*
Explains the technical realization, including the 3D modeling process in Blender and the integration of interaction logic in Unity for VR deployment.

Chapter 5: *Evaluation*
Details the design of the user study, the data collection method and presents the results gathered from participants.

Chapter 6: *Conclusion*
Summarizes the main findings, discusses them in relation to the research question and outlines possible directions for future work.

2 Background and Related Work

In this chapter, the theoretical and empirical foundations relevant to this thesis are presented. It begins with an overview of the Millikan oil-drop experiment, detailing its historical significance, experimental setup and educational relevance. This is followed by a discussion of Virtual Reality (VR), including its pedagogical potential, applications in physics education and considerations for effective instructional design. Finally, the chapter explores the role of visual detail in VR environments from a learning psychology perspective, highlighting how realism, cognitive load and user engagement interact to influence learning outcomes.

2.1 The Millikan Oil-Drop Experiment

The Millikan oil-drop experiment, conducted by Robert A. Millikan in 1909, is one of the most iconic experiments in physics. Its goal was to measure the elementary electric charge e by observing the motion of charged oil droplets in a controlled electric field. The experiment confirmed that electric charge is quantized, existing only in integer multiples of a fundamental unit [6].

The setup consists of two horizontal, parallel metal plates with a distance between them, creating a uniform electric field when a high-voltage DC power supply is applied. Between these plates, a fine mist of oil is sprayed using an atomizer. A small hole in the upper plate allows the oil droplets to pass through and enter the viewing region between the plates. Some of the droplets become electrically charged due to friction or by exposure to an ionizing radiation source, such as X-rays. The entire setup is enclosed in a transparent chamber, often with a microscope or telescopic eyepiece mounted horizontally to allow observation of individual droplets. An adjustable light source is used to illuminate the droplets, enhancing their visibility against a dark background [7].

The experiment relies on balancing the downward gravitational force and the upward electric force on a single droplet. By finely tuning the electric field, it is possible to suspend a droplet in mid-air. At this point, the forces are in equilibrium, and the charge on the droplet can be calculated as:

$$q = \frac{mg}{E}$$

where q is the electric charge on the droplet, m is its mass, g is the gravitational acceleration and E is the strength of the electric field (determined by the voltage and plate separation) [6].

To determine the mass m, Millikan used the droplet's terminal velocity in the absence of an electric field, applying Stokes' law to estimate the radius of the droplet from its falling speed through air [6, 7]. Combining the measurements under different conditions allowed him to deduce the discrete nature of electric charge.

The precision and clever design of the Millikan experiment made it a foundational study in modern physics and experimental methodology. Its relatively simple components make it a popular subject in physics education, although the physical setup and interpretation remain challenging for many students without visualization tools [8].

2.2 Virtual Reality

Virtual Reality (VR) refers to a computer-generated simulation of an interactive, 3D environment that users can explore and manipulate in real time. Typically experienced through head-mounted displays (HMDs) and motion-tracked controllers, VR allows users to perceive and interact with digital spaces as if they were physically present within them [1, 9]. This immersive quality is often achieved through the integration of stereoscopic visuals, spatial audio and natural user interfaces, all of which contribute to a compelling sense of presence, the psychological state in which individuals feel located within the virtual environment rather than the physical world [9, 10].

One of VR's defining features is its ability to provide embodied experiences that engage users in active exploration and sensorimotor interaction [11]. Unlike traditional screen-based media, VR supports spatial navigation, object manipulation and real-time feedback, which are critical for learning in domains that involve spatial reasoning or skill-based knowledge [2]. As such, VR is particularly well suited for educational contexts where physical experimentation, abstract concepts or complex systems are difficult to observe or replicate in real life [11].

The educational potential of VR is grounded in several theoretical foundations, including constructivist and experiential learning theories [12]. According to these perspectives, learners construct knowledge through direct experience and contextualized action. VR supports this process by offering controlled, repeatable and interactive environments in which learners can test hypotheses, visualize outcomes and receive immediate feedback [11, 12]. Additionally, the multisensory nature of VR has been shown to support deeper engagement and memory retention compared to traditional instructional methods [11].

Another important consideration in VR design is the level of visual fidelity, the degree to which the virtual environment realistically resembles the real world. While high-fidelity environments may enhance immersion and presence, they can also increase cognitive load or distract from learning goals [13]. Therefore, the effectiveness of VR applications in education often depends on how visual complexity, interactivity and instructional design are balanced to support specific learning outcomes [14].

Recent advances in software platforms such as Unity and Unreal Engine, as well as the increasing availability of affordable VR hardware, have made the development of educational VR applications more accessible. This has led to a surge in research exploring VR's impact across a wide range of fields including medicine, engineering, architecture and natural sciences [9]. Systematic reviews have highlighted the growing body of evidence supporting VR's role in enhancing student motivation, improving conceptual understanding and fostering positive learning attitudes [1].

2.2.1 VR in Physics Education

Physics education frequently involves abstract concepts and phenomena that are difficult to visualize or access in real-life classroom environments, such as electric fields, quantum effects or microscopic particles. These limitations can hinder intuitive understanding and engagement, particularly when learners cannot directly observe or interact with the phenomena being studied. This makes it particularly suited for virtual reality (VR) applications, which can simulate invisible processes and provide immersive, hands-on experiences that traditional methods cannot offer [1, 15].

Numerous studies have shown that VR-based instruction can enhance students' conceptual understanding, engagement and motivation [2, 16]. Wang et al. [15] reviewed 45 empirical studies and found that virtual experiments were most commonly used to support mechanics and electricity topics, where learners could interactively explore variables and visualize outcomes in real time. These simulations also help reduce the limitations of traditional experiments, such as equipment cost, safety risks or time constraints [15].

Furthermore, immersive VR enables multisensory interaction and embodied learning. Learners are no longer passive observers but can manipulate equipment, change parameters and receive immediate feedback through spatial interaction [16, 17]. This embodied form of learning has been associated with improved spatial reasoning and long-term memory, particularly in topics involving dynamic or 3D processes [11]. In this context, VR also supports diverse learning preferences, visual, auditory and kinesthetic, by combining stereoscopic graphics, sound and physical engagement [1, 16, 17].

These benefits extend into higher education, where VR has been shown to improve students' scientific thinking skills and self-efficacy, with a study by Villada Castillo et al. [16] demonstrating that undergraduate physics students using immersive VR environments performed significantly better in terms of conceptual understanding and reported a higher sense of presence and satisfaction compared to control groups using traditional media.

Instructional design plays a crucial role in the success of VR-enhanced learning. Well-structured tasks, user guidance and cognitive scaffolding are essential to prevent cognitive overload and ensure effective learning [11]. This is especially important in physics, where learners can become overwhelmed by interacting with too many variables or overly realistic simulations. Research emphasizes the need for balancing visual realism and usability to create effective VR learning environments [1, 17].

Moreover, integrating VR in physics education contributes to a shift toward inquiry-based and experiential learning. According to the review by Georgiou et al. [17], VR fosters students' scientific exploration skills by allowing them to test hypotheses, conduct experiments safely and observe physical laws unfold in real time. This supports constructivist learning principles, where knowledge is actively constructed through interaction and reflection.

A concrete example of this approach can be found in the work of Tarng et al. [18], who developed a series of virtual reality modules for teaching modern and quantum physics, including a fully interactive implementation of the Millikan oil-drop experiment. In their simulation, learners could adjust the electric field strength to suspend charged droplets in mid-air and calculate the elementary charge based on the balance between gravitational and electrical forces. The authors reported that students using the VR modules demonstrated higher learning gains, stronger motivation and lower cognitive load compared to those using conventional teaching materials. This finding highlights how immersive VR environments can make invisible physical processes (such as the motion of charged particles) directly observable and manipulable, thereby fostering deeper conceptual understanding and engagement. While Tarng et al. [18] focused primarily on comparing VR with traditional learning methods, the present thesis extends this line of research by systematically varying the level of visual detail within the VR environment itself to examine its specific impact on user experience and learning outcomes.

In addition to academic research, commercial VR platforms are also implementing classic physics experiments in immersive form. For example, VRLab Academy [19] offers a fully virtual version of the Millikan oil-drop experiment, where learners can spray charged oil droplets, adjust the voltage between capacitor plates, observe the droplets suspended in an electric field and compute the value of the electron's charge based on balanced forces. According to the platform description, the simulation allows measurement of voltage, droplet temperature, field strength and charge quantisation in a 3D lab setting. This demonstrates how immersive VR can replicate historically significant experiments with realistic procedural control and measurement capability. However, since this implementation is primarily a commercial product rather than a research study, it lacks detailed published empirical findings on how its levels of visual realism or user experience variations affect learning outcomes. The present work combines the educational potential of VRLab-style environments with a controlled investigation of how **environmental visual detail** influences cognitive load, presence and performance.

In summary, VR provides a unique platform for physics education by transforming abstract concepts into experiential learning scenarios. When designed thoughtfully, VR environments can not only supplement but enhance traditional instruction by offering students immersive, interactive and educationally rich experiences.

2.3 Level of Detail and Learning Psychology

The level of visual detail in virtual environments plays a crucial role in shaping user experience, cognitive processing and learning outcomes. In educational VR applications, detail refers not only to geometric complexity and texture realism, but also to the richness of environmental cues, interactivity and sensory feedback. While high levels of detail can increase realism and immersion, they may also impose higher cognitive demands on learners, potentially diverting attention from essential learning tasks [20, 21].

From a learning psychology perspective, the relationship between visual detail and learning effectiveness can be explained using *Cognitive Load Theory* (CLT). According to CLT, working memory has a limited capacity; excessive sensory input can result in extraneous cognitive load, which interferes with the processing of relevant instructional material [14]. In VR-based physics education, where learners may already be managing complex conceptual information, excessive environmental detail can overload cognitive resources. Wen et al. [14] demonstrated that attentional guidance methods in VR laboratories, such as visual highlights or reduced background complexity, significantly lowered cognitive load and improved academic performance, indicating the importance of managing detail in instructional design.

However, reducing detail indiscriminately can diminish learners' sense of presence and engagement. Kunz et al. [22] showed that immersive VR environments with carefully integrated visual realism improved both perceived realness and user motivation, provided that the complexity was aligned with the instructional goals. Similarly, Schrader et al. [23] found that hands-on VR training environments enhanced virtual presence, learning-centered emotions and cognitive engagement when the level of visual and interactive detail supported task relevance.

Spatial knowledge development is another critical factor influenced by visual detail. Cubukcu [20] demonstrated that higher visual detail improved users' ability to navigate and recall spatial layouts, particularly in complex environments. In physics VR scenarios, such as virtual laboratories or experiments, appropriate detail in spatial cues can aid learners in understanding equipment arrangement, experimental procedures and spatial relationships between components.

At the same time, research by Newman et al. [21] highlights that realism in virtual environments can enhance environmental engagement but must be balanced against the potential for distraction and increased processing demands. This suggests that optimal VR learning environments should feature a level of detail that supports presence and spatial understanding while minimizing irrelevant visual complexity.

In summary, the design of VR physics education environments should carefully balance realism and cognitive load. High-fidelity visuals can enhance immersion, spatial learning and motivation, but their benefits depend on alignment with learning objectives and the cognitive capabilities of learners. Thoughtful management of detail, through attentional guidance, task-relevant realism and purposeful simplification, can create VR experiences that are both educationally effective and psychologically sustainable.

3 VR Environment and Experiment Design

In this chapter, the focus is on explaining what was designed for the virtual simulation and the reasoning behind each design decision. It begins with the modeling of the Millikan oil-drop experiment and continues with the creation of three distinct virtual environments that differ in their level of visual detail. Each element, from spatial layout to visual realism and interactivity, was intentionally crafted to support clarity, immersion and experimental control. By describing both the design of the experiment and its surrounding environments, this chapter lays the groundwork for understanding the educational and experiential intentions behind the simulation. All textures and materials used in the modeling process were sourced from the online BlenderKit library [24], which provided high-quality, ready-to-use assets that enhanced the visual realism of the simulation.

3.1 The Millikan Oil-Drop Experiment Design

To visualize and simulate the Millikan oil-drop experiment in a virtual environment, a realistic and interactive 3D model of the experimental setup was created using Blender. Figure 3.1 shows the full virtual setup created for the simulation.

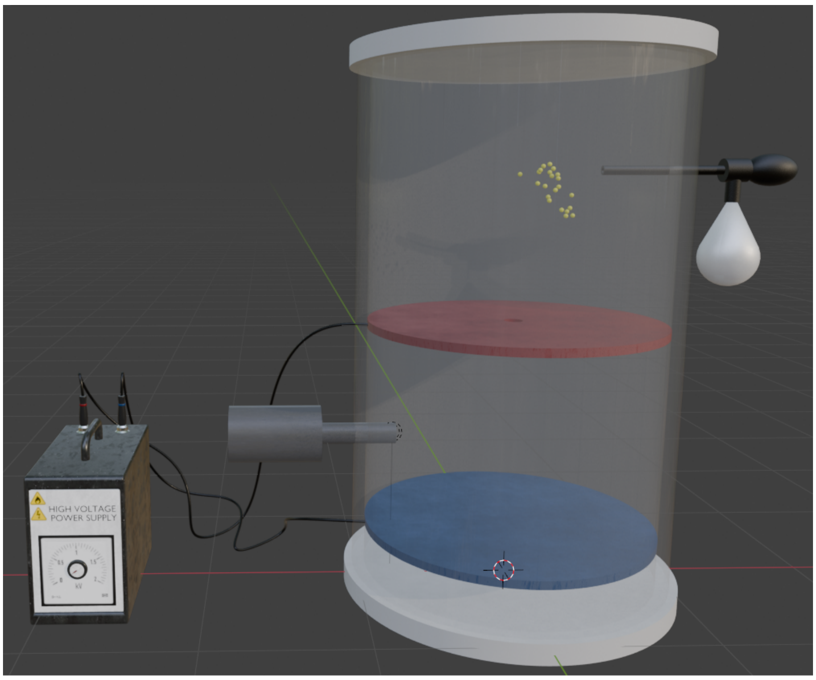

Figure 3.1: Full 3D model of the Millikan oil-drop experiment setup.

The setup consists of a vertically oriented transparent cylindrical chamber, enclosed by two white plates at the top and bottom. The transparent material allows the user to observe what is happening inside the chamber without relying on a traditional microscope or external light source. This choice is intended to enhance the immersive learning experience by allowing users to freely explore the experiment without being limited by specific viewing instruments, and to ensure that the external environment remains visible as part of the study's focus on visual context.

Inside the chamber are two horizontal plates made of metallic material, representing the positively and negatively charged components of the experiment. The upper plate is colored red to indicate a positive charge and includes a hole in the center through which the oil drops pass into the electric field. The lower plate is colored blue to reflect a negative charge. Both plates are connected to a high-voltage DC power supply, which provides the electric field required for the experiment. To simulate this connection, cables were modeled as part of the plates' geometry. Each cable is made of black silicone material and ends in a plug-like connector, visually inspired by real-world banana plugs used in laboratory setups. To help users recognize which cable is connected to which plate, a small red mark is added to the connector leading to the red (upper) plate and a blue mark to the one connected to the blue (lower) plate. Overall, the color choices on both plates and cables serve not only to enhance realism but also to act as cognitive cues, reinforcing the user's understanding of how the setup functions.

An X-ray source is positioned between the plates. This component includes a small light source to represent the emission of ionizing radiation, which electrically charges the falling oil drops. While the visual representation is simplified, it conceptually conveys the function of ionization to the user. The source itself is designed as a minimal, cylindrical metallic element to avoid distracting from the core experiment and to keep the user's focus on the behavior of the charged droplets rather than on technical complexity.

Attached to the side of the chamber is a mechanical atomizer, which was specifically designed to allow users to interact with it in the VR environment and spray oil drops into the chamber. To simulate this, an animation of falling oil droplets was created in Blender, which is triggered when the user presses the atomizer. Once activated, droplets appear inside the chamber, falling through the hole in the top plate and entering the electric field region, where they are influenced by gravitational and electrical forces.

The power supply is modeled in a classic analog style with a rotatable knob, which users can grasp and turn to adjust the voltage between the plates. Warning labels for electricity and fire hazard have been added to make the device appear more realistic and to simulate the sense of working with potentially dangerous laboratory equipment. To reinforce this retro appearance, a black, slightly faded metal material was used for the power supply's body, giving it a worn, industrial look reminiscent of traditional lab equipment. On the top panel, two connector sockets were also modeled to receive the cable plugs (one marked with red and the other with blue) visually indicating polarity and reinforcing the physical link between the plates and the power source.

This design intentionally simplifies certain elements, such as omitting a physical microscope and replacing it with transparent chamber walls, to align with the study's goal of evaluating how different environmental contexts, not visual complexity inside the apparatus, influence user experience. Each design decision was made to balance physical accuracy with interactivity and clarity for learners in a virtual environment.

3.2 VR Environment Design Approach

To enable a fair comparison across conditions, a single base room was modeled and reused for all three environments. The room includes only the essential architectural elements: a neutral floor, four plain walls, a simple ceiling and one door. Beyond this shared shell, additional elements (e.g. furniture, posters, windows, tools) are added or omitted according to the targeted level of environmental detail.

3.2.1 Low-Detail Environment

The low-detail environment, shown in Figure 3.2, is a simple and minimalistic space. It uses the shared base room with a single table centered in the room and the Millikan apparatus placed on top. No other furniture or props were modeled.

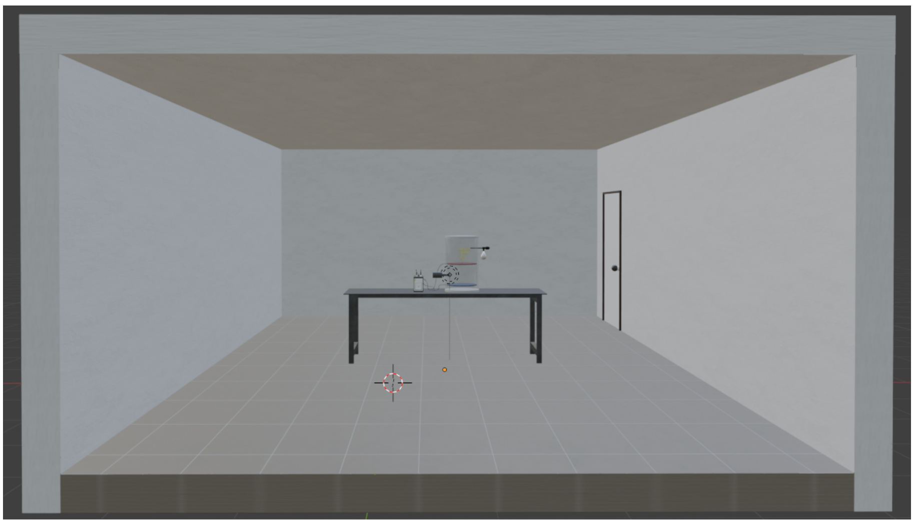

Figure 3.2: Low-Detail Environment.

The goal of this condition is to create a distraction-free space that isolates the experiment and keeps attention on the required interactions. By removing nonessential cues, this setting aims to minimize extraneous cognitive load and provide a baseline for comparison with the medium- and high-detail conditions, where only the surrounding detail is increased [14, 21].

3.2.2 Medium-Detail Environment

The medium-detail environment, shown in Figure 3.3, reuses the shared base room but is furnished to resemble a typical school or university classroom. Rows of lab tables with sinks and stools are arranged with a central aisle; a whiteboard and wall clock are placed on the front wall; and blue curtains line the side wall. Light desk items (e.g., papers, notebooks, a pen holder) are scattered on some tables to convey everyday use. The Millikan apparatus sits on the teacher's table at the front so the user stands facing the class while operating the experiment. Materials and colors are realistic but restrained, and lighting remains static.

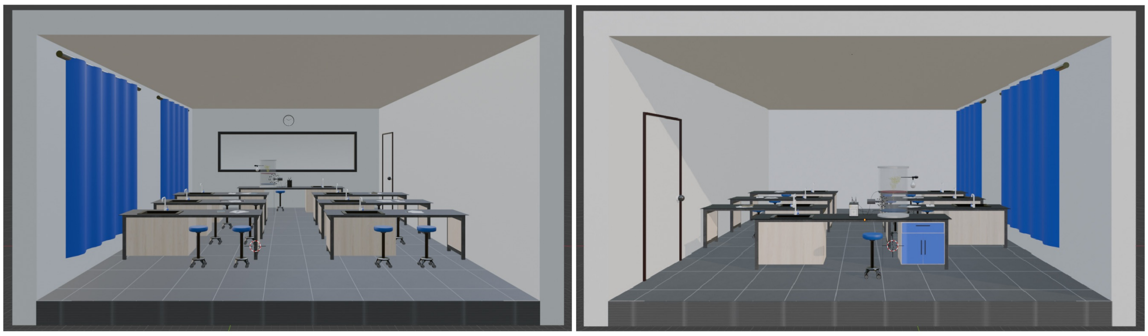

Figure 3.3: Medium-Detail Environment.

The goal of this environment is to provide a realistic, familiar context that increases presence and naturalness while keeping visual complexity moderate so attention remains on the experiment. This condition serves as a midpoint between the distraction-free low-detail room and the richer high-detail setting, allowing us to examine how adding everyday classroom detail affects focus, cognitive load and user experience [14, 21].

3.2.3 High-Detail Environment

The high-detail environment, shown in Figures 3.4 and 3.5, reuses the same base room but is modeled as a fully equipped laboratory. The space contains L-shaped tables and two rows of tables; cabinets, three wall posters, first-aid signage, two fire extinguishers, an AC unit, plant and two windows. Worktops are populated with varied lab equipment (e.g., microscopes, power supplies, test tubes), multiple desktop computers, stationery, books and notebooks, trash cans and other small objects. The Millikan apparatus is placed on the last row so that the user operates it while facing the room's richest visual area. Lighting remains static and interaction mechanics are identical to the other conditions; only environmental detail is increased.

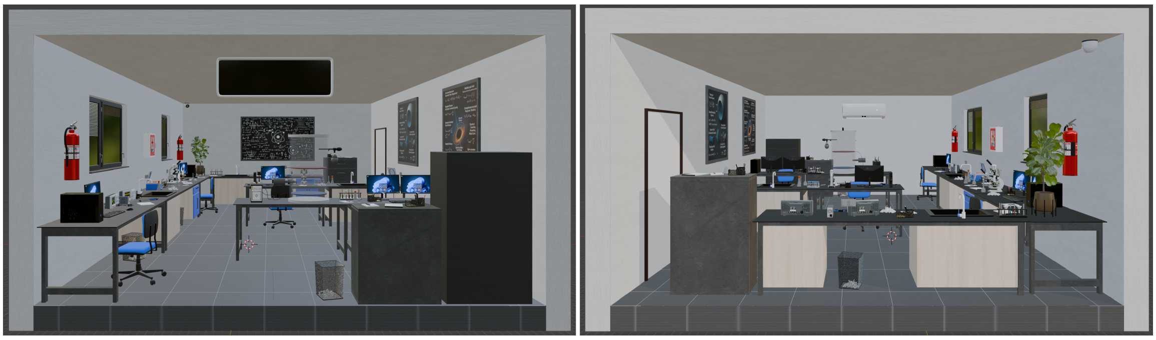

Figure 3.4: High-Detail Environment: front and back perspective view.

Figure 3.5: High-Detail Environment: top-down layout view

The goal of this environment is to create a visually rich, potentially distracting context that simulates an overstimulating learning environment. This condition is intended to raise visual saliency and ambient realism (potentially increasing presence) while testing whether additional, task-irrelevant detail draws attention away from the experiment and elevates extraneous cognitive load [14, 21].

4 Implementation

This chapter outlines the creation of the Millikan experiment, its three environment variants and the VR simulation. The process began in Blender, where the main components of the setup were modeled, including the chamber, power supply, atomizer, connecting plates and the oil-drop animation. The three environments (low-, medium-, and high-detail) were built from the same base room with progressively added visual elements. All assets were then exported to Unity, where the VR scenes were assembled. The project was configured with the required VR packages, and the XR Interaction Toolkit was used to implement interaction logic and user controls.

4.1 Blender Modeling

Blender[1] version 4.4 was used as the primary software for creating all 3D assets of the project, including the Millikan experiment apparatus and the virtual environments. It is an open-source 3D creation suite that provides comprehensive tools for modeling, texturing, shading and rendering, making it ideal for scientific visualization and educational simulations. Using Blender ensured a flexible and efficient workflow for designing detailed yet optimized assets that could later be integrated seamlessly into Unity for the VR implementation.

4.1.1 The Millikan Experiment Modeling

The chamber of the Millikan oil-drop experiment was modeled using basic mesh operations. A cylinder primitive was first added and scaled along the z-axis using the `S + Z` shortcut to create the initial vertical body of the chamber. This mesh was then duplicated with `Shift + D` and slightly rescaled to form a second cylinder, which was elongated again along the z-axis (`S + Z`). A Boolean difference modifier was applied to subtract the inner cylinder from the outer one, resulting in a hollow cylindrical shell with thin walls.

To achieve the transparent look of the observation chamber, a basic white material was assigned and its alpha value was adjusted in the shading workspace to 0.125. The chamber was closed at the top and bottom by adding two additional flat cylinders, which were scaled along the z-axis and positioned at both ends of the hollow structure. This produced a basic but functionally accurate chamber model that could later be integrated

[1] `https://www.blender.org/`

with the remaining apparatus components.

Inside the chamber, two parallel plates were added to represent the capacitor setup of the experiment. This was done by inserting a cylinder primitive, scaling it along the z-axis (`S + Z`) to make it thin, and then duplicating it with `Shift + D` to create the second plate. A simple color material was assigned to distinguish them: red for the upper plate and blue for the lower one. To simulate the small opening through which oil droplets could pass, a Boolean modifier was applied to cut a hole in the center of the upper plate.

On the right side of the chamber, the atomizer was modeled to resemble a small pump sprayer. Five cylinders were inserted and each was individually scaled and adjusted to form different parts of the nozzle and handle. Minor geometry modifications were applied to give the sprayer a more realistic contour. Finally, the meshes were combined into a single object using the `Ctrl + J` shortcut.

On the left side of the chamber, the X-ray source was constructed using two cylinders. The first was scaled down and elongated along the z-axis, then rotated to extend partially into the chamber, where its geometry was hollowed to simulate an opening for radiation emission. A second, larger cylinder was placed outside the chamber to act as the housing. The two meshes were joined into one object (`Ctrl + J`) and a gray metallic material from BlenderKit [24] was assigned. To simulate the effect of radiation, a light source was positioned within the smaller cylinder so that it projects into the chamber.

To connect the plates to the power supply, Bézier curves were used to model the wires. Each curve was placed in such a way that one end was aligned with the plate surface and the other end was attached to the terminals of the power supply. The curve geometry was then adjusted to follow a natural cable shape. To represent the banana plugs at the cable ends, two cylinder meshes were inserted, scaled down and further refined in *Edit Mode*. The bevel tool was applied to round the edges, creating the typical curved shape of the plugs. The plugs were later assigned a metallic material and placed inside the terminal sockets of the power supply.

The power supply unit itself was constructed from two cube primitives. The larger outer cube was scaled to form the casing and assigned a black metallic texture from BlenderKit [24], while a slightly smaller inner cube was inset on the front face to serve as the control panel, assigned a basic white material. Onto this front panel, several textures and labels were applied by projecting images directly onto the surface through the Shader Editor. This included a text label reading “High Voltage Power Supply”, two warning icons (fire and electricity symbols), and a circular voltage scale represented by a PNG image. Each image was loaded into an Image Texture node and connected to the material's Base Color input, then aligned precisely on the panel using UV mapping adjustments. Finally, a simple cylinder mesh was added as the control knob and positioned at the center of the voltage scale.

Additionally, a handle was modeled on the top of the power supply. This was achieved by adding three cylinders, scaling them into elongated segments and connecting them in *Edit Mode* using the Bridge Edge Loops function to create a continuous curved form. The handle was given the same black metallic material as the casing, ensuring visual consistency with the overall design.

The final component of the apparatus was the representation of the oil droplets and their motion. To model the droplets, a UV sphere primitive was added, scaled down to a very small size using the `S` shortcut, and assigned a dark yellow material to reflect the typical color of oil. This initial sphere was then duplicated (`Shift + D`) 21 times to generate a set of droplets for the simulation.

To animate the droplets, the *Follow Path* constraint in Blender was used. A separate curve path was created for each droplet, with the starting point aligned at the nozzle of the atomizer to simulate spraying. Of the 22 droplets, 18 were animated to travel directly toward the upper (red) capacitor plate, where their paths ended on the surface. The remaining 4 droplets were assigned longer paths that continued through the small hole in the upper plate and into the region between the two plates, simulating the entry of charged droplets into the electric field.

All droplets were animated over the same time interval, from frame 0 to 100, corresponding to approximately 4.14 seconds of animation time. This ensured a synchronized release from the atomizer, while the variation in path lengths distinguished those droplets that entered the field region from those that did not. In this way, the animation recreated the physical behavior of the experiment, where only a small fraction of the sprayed oil drops pass through the aperture and become subject to the balance of gravitational and electric forces.

As a final step, all meshes used in the apparatus were smoothed to remove sharp edges and achieve a more realistic appearance. For this, the *Subdivision Surface* modifier was applied to each object. The *Levels Viewport* parameter was adjusted individually depending on the geometry of the mesh and the number of edges it contained, ensuring smooth curvature while keeping the model efficient for rendering and later use in Unity. This process gave the chamber, plates, atomizer, power supply and oil droplets a more polished and visually coherent appearance, suitable for an immersive VR environment.

4.1.2 The Environments Modeling

The starting point for all three environments was the creation of a shared base room. This was modeled using simple cube meshes. First, a cube was added and scaled to form the right wall of the room. This mesh was then duplicated with `Shift + D` and placed on the opposite side to create the left wall, both having greater length than the front and back walls. A similar process was repeated to construct the front and back walls by duplicating and resizing cube meshes to match the shorter dimensions. Finally, additional cubes were scaled and positioned to form the ceiling and the floor, completing a closed rectangular room structure.

For materials, the walls and ceiling were assigned a white plaster texture from BlenderKit [24], while the floor was given a tiled floor material, also from BlenderKit. On the right wall, a simple door was created by adding another scaled cube and placing it flush with the wall surface. A UV sphere, scaled down and positioned accordingly, served as the door knob. The result was a minimal yet realistic rectangular room that served as the base environment for all three levels of detail.

Low-detail environment:

For the low-detail environment, the previously created base room was used without any additional furniture or decorative elements, except for a single table placed at the center of the room. The base of the table was imported directly from BlenderKit [24] and positioned along the central axis of the floor. To complete the table design, a cube mesh was added and scaled to form the tabletop. A black wood material was then assigned to the surface, providing a subtle contrast against the neutral room background.

Medium-detail environment:

For the medium-detail environment, the same base room was used as a foundation, but it was enhanced with additional classroom elements to create a moderately realistic learning setting. All furniture and props were sourced from BlenderKit, including laboratory tables, chairs, books, papers, a whiteboard, a wall clock and curtains.

To construct the scene, each object was duplicated using the `Shift + D` shortcut to achieve the appropriate quantity for a typical classroom layout. A total of seven laboratory tables were arranged, six for students and one teacher's table positioned at the front. Two laboratory chairs were placed at each student table, and multiple books and sheets of paper were scattered across the tabletops to enhance visual authenticity while maintaining moderate detail.

Object positioning was performed using the `G` shortcut (Grab) to move items freely, and the `G + X` and `G + Y` constraints were used to align furniture precisely along the horizontal axes. Curtains were duplicated and placed along the left wall, while the whiteboard and wall clock were mounted on the front wall to resemble a conventional classroom.

Finally, the materials and colors of most objects were adjusted to ensure a consistent and realistic appearance. Although each BlenderKit asset included its own textures, minor adjustments were made to harmonize their tones so that no single element appeared visually out of place. The resulting environment achieved a balanced level of realism, rich enough to feel natural and immersive, yet not visually overwhelming, aligning with the design goals of the medium-detail condition.

High-detail environment:

For the high-detail environment, the same base room served as the foundation, but it was populated with a larger number of objects and finer visual details to create the impression of a realistic laboratory. All items, such as laboratory tables, computers, microscopes, instruments, books, chairs, plants and storage units, were sourced from BlenderKit [24]. Each object was duplicated (`Shift + D`) and arranged carefully to achieve a dense yet organized laboratory layout. The overall goal was to simulate a highly detailed space filled with visual elements, providing a natural sense of complexity and visual engagement.

To integrate additional architectural features, two windows were modeled on the left wall using the *Boolean Difference* modifier, which allowed the window meshes to fit seamlessly into the wall geometry. Three wall posters were also created to enhance the scientific atmosphere of the room. To design them, three physics-related images were imported into Blender as textures and applied onto scaled rectangular planes. The images were UV-mapped precisely to fit the surface, and a slight glossy shader was added to imitate the reflective surface of printed posters.

As with the other environments, most materials and colors were adjusted to ensure visual coherence and realistic lighting reflection. The Millikan experiment setup was positioned on the second row of tables, facing the rest of the laboratory objects, so that the user's field of view during interaction was exposed to a large number of visual details. This intentional placement helped ensure that the participant experienced a highly stimulating and visually complex environment, providing the richest visual context among the three VR conditions.

4.2 Unity and Interaction Techniques

The virtual reality implementation of the Millikan oil-drop experiment and its environment variants was developed using the Unity Editor version 2022.3.62f1 (LTS). Unity[2] served as the main development platform for scene assembly, lighting, material adjustment and interaction logic.

Several Unity packages were installed to enable VR functionality and interaction. The most relevant were the *XR Interaction Toolkit*[3], the *OpenXR Plugin*[4], the *Oculus XR Plugin*[5] and the *XR Hands* package[6]. Together, these packages provided compatibility with standalone headsets such as the Meta Quest 3, supporting hand tracking, controller input and object interaction features.

The project hierarchy was structured around an *XR Origin (XR Rig)* that included the main camera and controller setups for both hands. Interaction management was handled through the *XR Interaction Manager*, while teleportation, object grabbing and hand visualization were configured using components provided by the XR Toolkit. This modular setup ensured a stable and responsive interaction system suitable for evaluating user performance and experience in all three environmental conditions.

Importing Blender Models into Unity

The 3D assets created in Blender were imported into Unity for scene assembly and interaction setup. The most common and reliable export formats for transferring models between Blender and Unity are `.fbx` and `.glb`, both of which preserve geometry, scale and basic material properties. In cases where a model contains only a few materials, missing textures can easily be reimported or reassigned manually within Unity.

However, this approach became impractical for the medium- and high-detail environments, which contained thousands of individual materials and textures. Manually extracting and reassigning them from Blender was not feasible. To address this, each

[2] `https://unity.com/`
[3] `https://docs.unity3d.com/Packages/com.unity.xr.interaction.toolkit@3.0/manual/index.html`
[4] `https://docs.unity3d.com/Manual/xr-openxr.html`
[5] `https://docs.unity3d.com/Packages/com.unity.xr.oculus@3.0/manual/index.html`
[6] `https://docs.unity3d.com/Packages/com.unity.xr.hands@1.3/manual/index.html`

complete model (the Millikan experiment, the low-detail environment, the medium-detail environment and the high-detail environment) was exported in three different formats: `.fbx`, `.glb` and `.blend`. Each format retained a different subset of materials when imported into Unity.

After comparing the results, the `.fbx` format preserved the largest number of materials accurately. The missing materials were then reassigned manually by referencing the corresponding `.glb` and `.blend` imports. This hybrid approach ensured that, in the final Unity project, all objects across the four models displayed their correct materials and textures without visual inconsistencies.

To enhance environmental realism in the high-detail environment, a skybox was implemented to simulate an outdoor scene visible through the laboratory windows. This addition ensured that participants perceived a natural background rather than the default gray void of the Unity scene, thereby increasing visual immersion and spatial coherence. The skybox used in this project was the *Bethnal Green Entrance* HDRI from Poly Haven[7].

Interaction Setup in Unity

After all models were successfully imported into Unity, a reference plane was added to the scene to ensure that all environments were aligned on a consistent ground level. This allowed the user to stand naturally on the virtual floor when wearing the VR headset and prevented floating or misaligned geometry during testing.

The primary interactive element in the simulation was the atomizer pump, which triggered the animation of the oil droplets when pressed. To enable this interaction, a *Box Collider* and a *Rigidbody* component were added to the pump object to define its physical boundaries and allow it to respond to user input. The collider was carefully adjusted to match the shape of the pump, while the rigidbody was configured with appropriate mass and drag values to ensure realistic movement. An *XR Simple Interactable* component was then attached to the pump and linked to the *XR Interaction Manager*, allowing the user to interact with the pump using VR controllers or hand tracking.

To connect the spray interaction with the oil-drop animation, the animation sequence created in Blender was imported into Unity along with the experiment model. Under the model's import settings, the *Import Animation* option was enabled to ensure that all keyframes were transferred correctly. A new *Animator Controller* was then created and assigned to the oil-drop object. Within the Animator window, an animation state

[7] `https://polyhaven.com/a/bethnal_green_entrance`

machine was configured with an *Idle* state and an active state linked to the imported animation clip. The transition between these states was set to be triggered by an event from the *XR Simple Interactable* component.

When the user grabbed and pressed the pump in VR, the interaction event triggered the transition in the Animator, which in turn played the oil-drop animation sequence. This established a complete interaction loop between the user's physical action and the corresponding visual response, accurately replicating the atomization process of the real Millikan oil-drop experiment. The result was a tactile and intuitive interaction mechanism that reinforced the educational focus of the simulation through hands-on engagement.

In addition to the spray interaction, a second interactive element was implemented to simulate the adjustment of the electric field strength using the voltage control knob on the power supply. This interaction was designed to help users observe the relationship between electric field intensity and the motion of the oil droplets.

A *Box Collider*, *Rigidbody* and *XR Simple Interactable* component were added to the knob, allowing it to be selected or held using the VR controller. To control the behavior of the oil-drop animation based on the user's input, a custom C# script named *HoldToSlowAnimator.cs* was developed. The script dynamically modifies the playback speed of the oil-drop animation according to the user's interaction state.

When the knob is held down (by pressing the left controller), the script detects the interaction event and gradually reduces the animation speed by adjusting the animator's playback rate. This simulates the effect of applying a higher voltage, during which the droplets slow down, giving the radiation time to charge the particles. Once the user releases the knob, the animation returns smoothly to its normal speed.

This feature added an additional layer of interactivity and educational value by allowing users to directly experience how changes in the electric field influence droplet movement, reinforcing the conceptual understanding of the experiment's physical principles.

5 Evaluation

This chapter presents the results of the user study conducted to examine how different levels of visual detail in the virtual reality environments affected participants' learning, perceived workload, user experience, sense of presence and evaluation of the environment. 30 students participated in the study, each experiencing one of three environments (low, medium or high detail). The following sections describe the participants, study design, procedure and summarize the main findings from the collected questionnaires and performance tests.

5.1 Participants

A total of 30 participants took part in the user study. The group consisted of 13 female and 17 male students, all enrolled at Otto-von-Guericke University Magdeburg. Their ages ranged from 20 to 29 years, with a mean age of approximately 24 years. All participants were studying in engineering-related programs, including electrical, mechanical and medical engineering. Among them, 16 were master's students and 14 were bachelor's students.

To ensure an unbiased distribution across the three experimental conditions, participants were randomly assigned to one of the three VR environments representing different levels of visual detail (low, medium and high). Randomization was achieved by drawing one of three folded papers labeled with the numbers 1, 2 or 3, corresponding to the respective environment type. Each participant thus experienced exactly one version of the simulation.

Regarding prior experience with virtual reality systems, two participants reported having used VR multiple times, seven participants had used VR once before and eleven participants had no prior experience with virtual reality. This information was gathered to adapt the introductory explanation and ensure that all participants were equally comfortable with the basic VR interactions before starting the simulation.

All sessions were conducted using a *Meta Quest 3* standalone VR headset[1], providing six degrees of freedom and high visual fidelity. The device features a per-eye resolution

[1] https://www.meta.com/quest/quest-3/

of 2064 × 2208 pixels and a refresh rate of up to 120 Hz, ensuring smooth interaction and visual consistency across participants. Each participant completed the experiment individually under supervised conditions in a controlled laboratory setting to ensure consistency and minimize external distractions.

5.2 Study Design

The user study was designed to examine the effect of varying levels of visual detail in virtual reality environments on learning outcomes, perceived cognitive workload, user experience and presence. The study followed a between-subjects design with three experimental conditions (low-, medium- and high-detail environment), each assigned to ten participants. The independent variable was the level of environmental detail, while the dependent variables were derived from the results of the pre- and post-knowledge tests, as well as the standardized questionnaires administered after the simulation.

Each participant completed five instruments in total: the Millikan knowledge test (administered both before and after the simulation), the NASA Task Load Index (NASA–TLX), the User Experience Questionnaire (UEQ), the Igroup Presence Questionnaire (IPQ), and the VR Environment Questionnaire. All questionnaires were provided in printed form and completed immediately after the VR session under supervision to ensure consistency in data collection. The complete versions of all questionnaires are included in the Appendix under the chapter *Questionnaires* A, and the collected response data used for analysis are provided in the chapter *Questionnaire Data Spreadsheets* C.

Millikan Test

The pre- and post-knowledge test was used to assess participants' understanding of the Millikan oil-drop experiment before and after the VR simulation. The test consisted of ten multiple-choice questions related to the fundamental physical concepts of the experiment, such as the forces acting on the oil droplets and the purpose and effect of the electric field. The test was originally developed by a secondary school teacher and later adapted for use in this study to match the experimental learning objectives. Each correct answer was scored with one point, resulting in a maximum possible score of ten. The difference between post- and pre-test scores was used as a measure of learning improvement.

NASA Task Load Index

The NASA Task Load Index (NASA-TLX) is a standardized instrument for assessing subjective workload, developed by Hart and Staveland [25]. It evaluates perceived workload across six dimensions: *Mental Demand*, *Physical Demand*, *Temporal Demand*, *Performance*, *Effort* and *Frustration*. Each dimension was rated on a continuous 21-point scale with descriptive verbal anchors defining the endpoints of the scale. Lower scores represent a more positive evaluation, indicating lower perceived workload or higher task success.

In this study, the NASA-TLX was used to evaluate how demanding the simulation was for participants, both mentally and physically, as well as how successful and efficient they felt during the experiment. Each participant's workload score was calculated as the mean value across all six dimensions. The aggregated mean workload per environment (low, medium, high detail) was later used to compare perceived task load between the different visual conditions.

User Experience Questionnaire

The User Experience Questionnaire (UEQ) is a scientifically validated instrument designed to assess the overall user experience of interactive systems [26]. It distinguishes between two main components of user experience: the *pragmatic quality*, which reflects aspects such as efficiency and clarity, and the *hedonic quality*, which refers to stimulation and originality. The questionnaire uses bipolar adjective pairs such as *complicated–easy*, *inefficient–efficient* or *boring–exciting* to capture users' impressions.

In this study, the short version of the UEQ was employed, consisting of eight items rated on a seven-point semantic differential scale, where higher values indicate a more positive evaluation. The short version was chosen because it is particularly suitable for comparing different variants of a system after short interactions, as it efficiently captures the users' immediate perception of usability and enjoyment. For each participant, the mean UEQ score was calculated to represent the overall user experience within the respective virtual environment.

Igroup Presence Questionnaire

The Igroup Presence Questionnaire (IPQ) is a standardized instrument used to assess the subjective sense of presence in virtual environments [27]. It measures perceived presence across four dimensions: *general presence*, which represents the overall sense of being there; *spatial presence*, which reflects the feeling of being physically located within the virtual space; *involvement*, which captures the degree of attention and engagement; and *experienced realism*, which assesses how realistic the environment appears.

Each item is rated on a seven-point Likert-type scale ranging from *fully disagree* (–3) to *fully agree* (+3). For each participant, individual mean scores were calculated for the four dimensions, as well as an overall mean presence score representing the participant's general experience of immersion within the simulation.

VR Environment Questionnaire

In addition to the standardized instruments, a short custom questionnaire was developed specifically for this study to assess the perceived qualities of the virtual environments. The VR Environment Questionnaire consisted of four statements rated on a seven-point Likert scale (1 = *strongly disagree*, 7 = *strongly agree*). The items addressed participants' general liking of the environment, perceived helpfulness for learning, perceived disruption during the learning process, and their desire for additional interactivity within the virtual space.

This instrument was designed to capture participants' subjective impressions of the environment's visual detail and its influence on the learning experience. For analysis, the item assessing perceived disruption to learning was reverse-coded to align directionally with the other items, such that higher values consistently indicated a more positive evaluation of the environment. An overall mean score was then calculated to represent each participant's general satisfaction with the respective virtual environment.

5.3 Procedure

At the beginning of each session, participants were welcomed and briefly introduced to the purpose and structure of the study. They were first asked whether they had any prior experience with virtual reality systems to adapt the explanation if necessary. After this short introduction, each participant completed the pre-knowledge test on the Millikan oil-drop experiment to assess their initial understanding of the topic.

Following the pre-test, participants received a standardized explanation of how to navigate and interact within the virtual environment. Specifically, they were instructed on how to use the teleportation system to move around the room, how to hold and press the right controller to operate the atomizer that releases the oil droplets, and how to hold the left controller to apply the high voltage that controls the electric field. Once this short training was complete, participants were asked to explore the virtual environment freely to familiarize themselves with the spatial setup and level of detail.

When ready, participants proceeded to the Millikan experiment setup within the virtual environment. At this point, a predefined verbal explanation of the experiment was presented. This explanation was identical for all participants, regardless of the environment condition, and included an overview of the physical forces acting on the oil droplets, the purpose of the electric field and its influence on droplet motion. The complete script of this oral explanation is provided in the Appendix under the Chapter *Oral Explanation Script* B.

After completing the experiment, participants were asked to fill out a series of standardized questionnaires in printed form. These included the NASA Task Load Index (NASA-TLX), the User Experience Questionnaire (UEQ), the Igroup Presence Questionnaire (IPQ) and the VR Environment Questionnaire. Finally, participants completed the post-version of the Millikan knowledge test, which was identical to the pre-test administered at the beginning of the session. This allowed a direct comparison of learning outcomes before and after the virtual experiment.

The total duration of the entire session ranged between approximately 19 and 27 minutes, depending on the environment and the individual participant. Participants in the more detailed environments tended to spend additional time exploring or observing virtual objects, whereas those in the low-detail environment generally proceeded more directly to the experimental task. Small variations in duration also resulted from individual differences in response time during the questionnaires.

5.4 Results

This section presents the key findings of the user study, summarizing participants' learning outcomes and subjective evaluations across the three virtual environments. The results are structured according to the main instruments used in the study, beginning with the Millikan knowledge test and followed by the NASA–TLX, UEQ, IPQ and VR Environment Questionnaire. Together, these findings provide an overview of how different levels of environmental detail influenced learning performance, workload, user experience, sense of presence and perceived environment quality.

Learning Outcome

Figure 5.1 illustrates the mean improvement in participants' test scores on the Millikan knowledge test before and after completing the VR simulation. The improvement score was calculated for each participant as the difference between the post-test and pre-test results, representing the individual learning gain achieved through the virtual experiment.

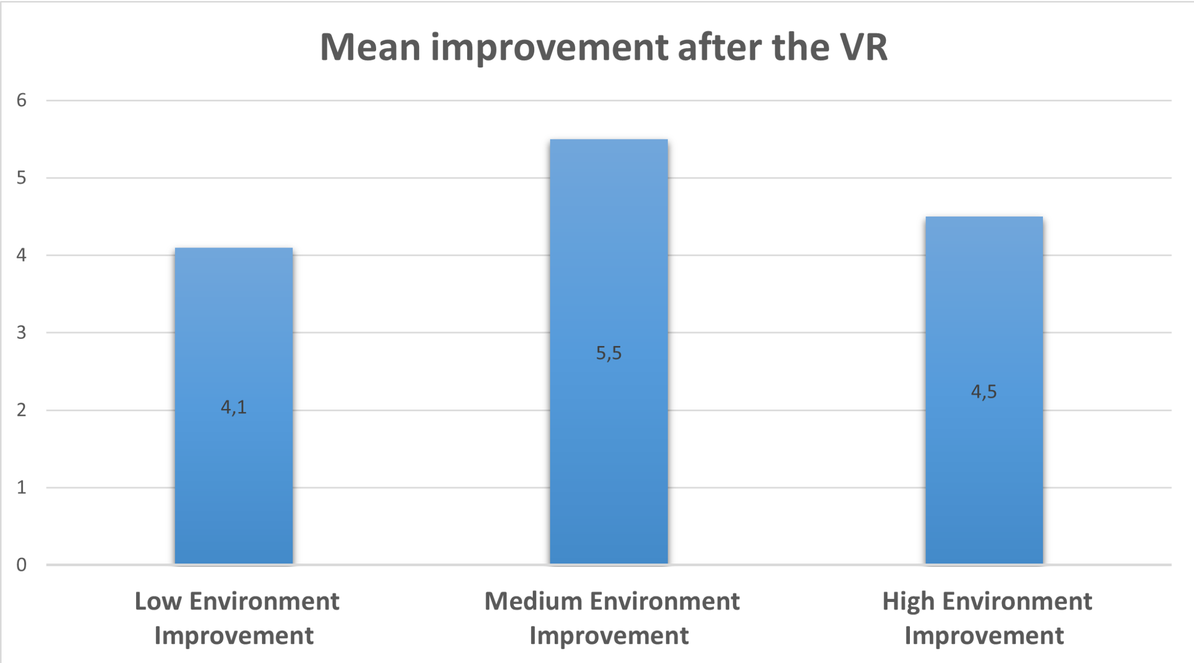

Figure 5.1: Millikan Test Improvement Result

As shown in figure 5.1, all three environments led to a measurable increase in test performance, indicating that the VR simulation effectively supported conceptual understanding of the Millikan oil-drop experiment. Participants in the medium-detail environment achieved the highest mean improvement (M = 5.5), followed by those in the high-detail environment (M = 4.5) and the low-detail environment (M = 4.1). Although the differences between the groups were relatively small, the trend suggests that a moderate level of visual detail may provide an optimal balance between clarity and engagement for effective learning.

Perceived Workload

The upper chart in Figure 5.2 presents the mean ratings for the six NASA–TLX workload dimensions across the three virtual environments. Overall, participants reported moderate workload levels in all conditions. The highest ratings were observed for *Mental Demand*, indicating that the task required focused attention and sustained cognitive engagement, while the lowest ratings were found for *Performance (Reversed)*, reflecting that participants generally felt they performed well within the VR simulation.

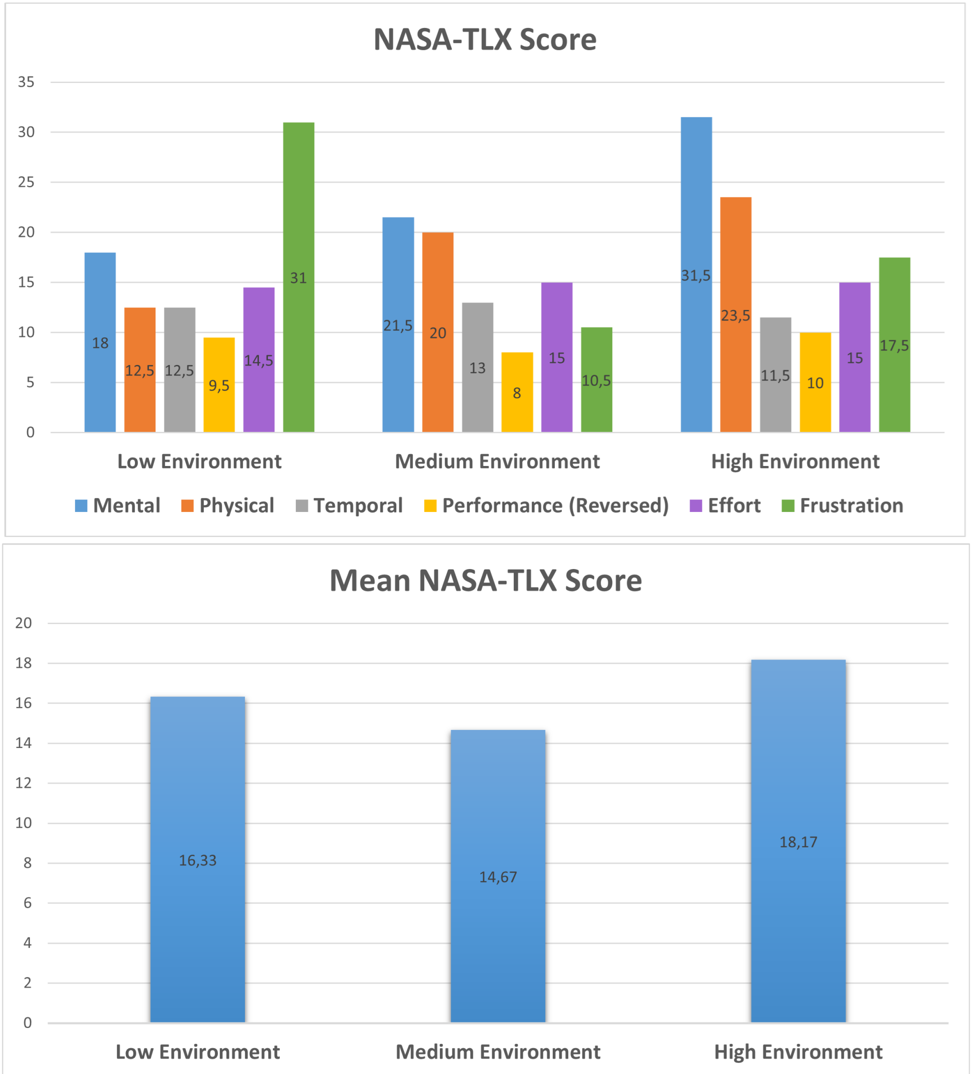

Figure 5.2: NASA TLX Questionnaire Results

The lower chart in Figure 5.2 shows the overall mean NASA–TLX scores for each environment. The workload was lowest for the medium-detail environment (M = 14.67), slightly higher for the low-detail environment (M = 16.33) and highest for the high-detail environment (M = 18.17). This pattern suggests that participants perceived the medium-detail environment as the least demanding, while the high-detail environment imposed a somewhat higher mental and physical workload.

User Experience

The upper chart in Figure 5.3 shows the mean ratings for the two dimensions of the User Experience Questionnaire (UEQ): *Pragmatic Quality* and *Hedonic Quality*. All environments received positive evaluations, indicating that participants found the simulation both usable and enjoyable. *Pragmatic Quality* was rated highest for the low-detail environment (M = 2.33), suggesting greater clarity and ease of use, while *Hedonic Quality* peaked in the high-detail environment (M = 2.65), reflecting higher stimulation and enjoyment in visually richer conditions.

Figure 5.3: User Experience Questionnaire Results

The lower chart in Figure 5.3 shows the overall user experience scores for each environment. The results were consistently positive, with mean values of 2.175 for the low-detail, 2.300 for the medium-detail and 2.343 for the high-detail environment. This pattern suggests that while all environments offered a satisfying user experience, higher visual detail contributed slightly to enhanced enjoyment without reducing perceived usability.

Sense of Presence

The upper chart in Figure 5.4 shows that participants reported positive presence levels across all four IPQ dimensions. The strongest values were observed for *General Presence*, which increased from the low- to the high- and then medium-detail environments. *Spatial Presence* remained relatively constant across conditions, while *Involvement* and *Experienced Realism* showed a slight upward trend with increasing visual detail. These results indicate that higher graphical fidelity modestly enhanced participants' sense of being part of the virtual scene and their perception of realism.

Figure 5.4: Igroup Presence Questionnaire Results

The lower chart in Figure 5.4 shows the overall presence score, calculated as the mean of the four dimensions. Presence was lowest for the low-detail environment ($M = 0.42$) and higher for the medium-detail ($M = 1.20$) and high-detail ($M = 1.15$) environments. This indicates that participants experienced a stronger sense of presence in visually richer environments, although the difference between the medium- and high-detail conditions was minimal.

Perceived Environment Quality

The upper chart in Figure 5.5 shows the mean ratings of the four items from the VR Environment Questionnaire across the three virtual environments. Participants evaluated all environments positively, with the highest ratings for *Liked the environment* and *Not disruptive to learning*. The item *Helped settle* also received relatively high values, suggesting that both the medium- and high-detail environments supported user comfort and orientation. The lowest ratings were given to *Wanted more interaction*, indicating that most participants were satisfied with the existing level of interactivity.

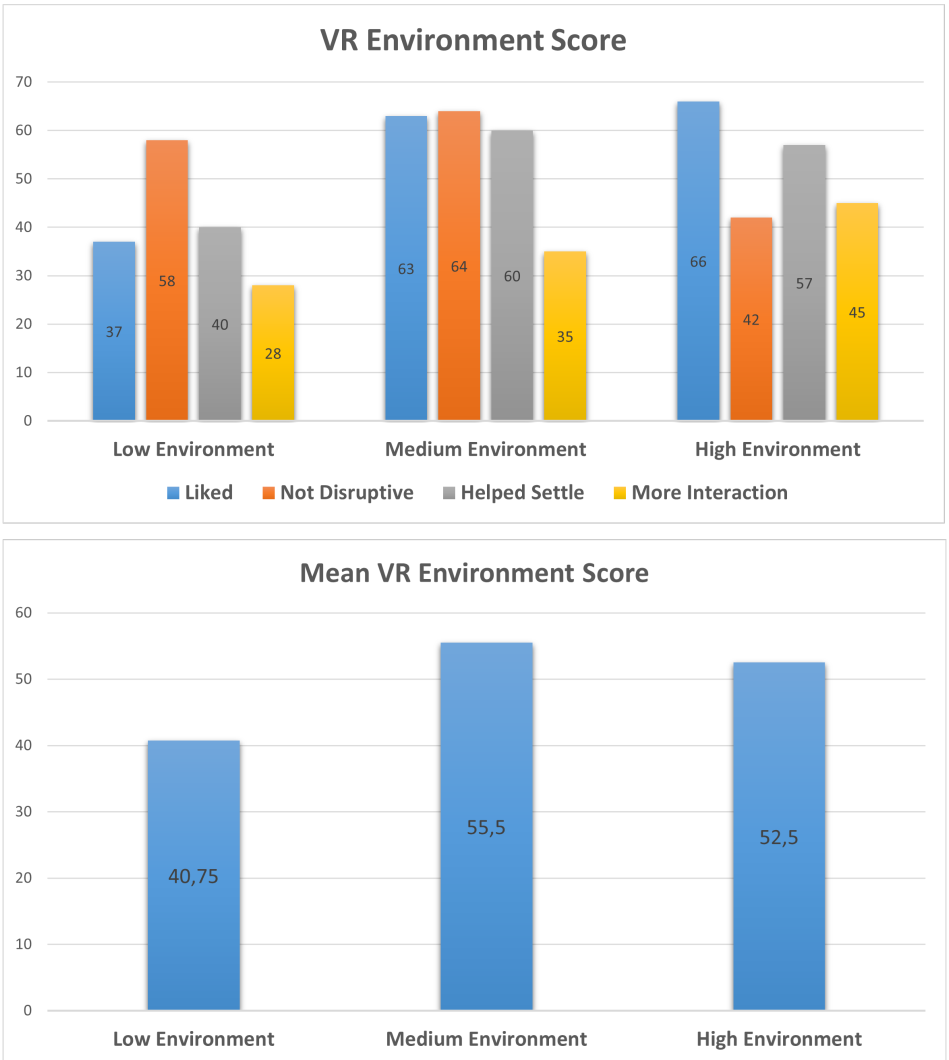

Figure 5.5: VR Environment Questionnaire Results

The lower chart in Figure 5.5 presents the overall satisfaction score for each environment. The low-detail environment received the lowest rating ($M = 40.75$), the medium-detail environment achieved the highest ($M = 55.5$) and the high-detail environment scored slightly lower again ($M = 52.5$). This suggests that a moderate level of visual detail provided the most favorable overall impression, while both minimal and excessive detail slightly reduced perceived satisfaction.

6 Conclusion

This final chapter integrates and reflects upon the findings of the conducted study on how varying levels of visual detail in virtual reality environments influence learning outcomes and user experience in the context of the Millikan oil-drop experiment. It begins with a discussion of the main results and their implications, followed by an examination of the study's limitations and methodological considerations. The chapter concludes with suggestions for future research and potential improvements for educational VR applications.

6.1 Discussion

The results of this study demonstrate that the level of visual detail in a virtual physics experiment can influence both user experience and cognitive factors, though its effect on learning outcomes was less pronounced. Overall, all three environments (low, medium and high detail) proved effective in supporting participants' understanding of the Millikan oil-drop experiment, with measurable improvements between pre- and post-test scores. This suggests that the VR simulation itself, regardless of graphical fidelity, successfully facilitated conceptual learning by enabling students to visualize and interact with abstract physical processes such as charged particle motion and electric field forces.

The comparison across visual detail levels revealed that participants in the medium-detail environment achieved the highest learning gains and reported the lowest workload on the NASA–TLX scale. This finding aligns with cognitive load theory, which suggests that excessive visual detail may increase extraneous cognitive processing, while insufficient detail can reduce contextual cues necessary for comprehension. The medium-detail environment therefore appears to offer an optimal balance between realism and clarity, enabling focused engagement without visual distraction.

Regarding user experience, all environments were rated positively, but higher visual detail enhanced hedonic quality, reflecting increased enjoyment and stimulation. This pattern is consistent with studies such as Tarng et al. [18], who found that immersive visual representations in VR physics simulations increased learner motivation and perceived engagement. Similarly, the sense of presence measured by the IPQ increased with graphical fidelity, supporting the idea that visual realism contributes to stronger feelings of immersion and spatial awareness [17]. However, the differences between the medium- and high-detail conditions were minimal, indicating diminishing returns once a sufficient level of realism is achieved.

The results of the VR Environment Questionnaire further emphasize that participants favored environments that balanced detail and usability. The medium-detail environment received the highest satisfaction ratings, suggesting that moderate realism not only supports learning but also fosters comfort and focus within the simulation. Interestingly, participants expressed little desire for additional interactivity, indicating that the existing level of manipulation and feedback was sufficient for maintaining engagement and achieving the learning objectives.

Taken together, these findings contribute to the broader understanding of design trade-offs in educational VR. They highlight that more realism does not necessarily lead to better learning outcomes, and that cognitive efficiency may depend on providing only the visual detail necessary for task comprehension. This insight is particularly relevant for educational developers, as it underscores the importance of aligning visual fidelity with instructional goals rather than aesthetic appeal.

In summary, the results of this study demonstrate that virtual reality can effectively support the understanding of complex physical phenomena such as the Millikan oil-drop experiment by providing interactive and visually accessible representations of otherwise abstract processes. Across all experimental conditions, participants showed measurable learning gains and positive user experiences, confirming the educational potential of VR in physics instruction. At the same time, the comparison between different visual-detail levels revealed that moderate graphical fidelity yields the most favorable balance between cognitive efficiency, presence and enjoyment. While higher realism further increased immersion, it also tended to raise perceived workload without corresponding improvements in learning performance. These outcomes reinforce previous research on VR-based physics education [1, 11, 15, 17, 18] and contribute empirical evidence that thoughtful visual design (rather than maximum realism) is crucial for optimizing both cognitive and experiential aspects of learning in virtual laboratory environments.

6.2 Limitations

Although the developed VR simulation successfully achieved its educational objectives, several limitations should be acknowledged. The first relates to the interaction design of the voltage control knob on the power supply. Ideally, the knob would be rotatable, allowing users to continuously adjust the voltage and observe corresponding changes in the electric field. A prototype of this feature was implemented using a custom C# script, similar to the interaction used for pressing the knob to control animation speed. However, the rotation behavior proved unstable: the angle mapping was inconsistent, and the animation could not be reliably synchronized with the knob's position. As a result, the final version retained the simpler press-based interaction rather than full rotation.

A second limitation concerns the scope of the animation control. In the current implementation, activating the voltage control affects all oil droplets in the scene simultaneously. In a more precise simulation, only the droplets passing through the hole in the upper plate (those within the electric field) should respond to changes in voltage. This limitation arose from the way the animation sequence was structured in Blender and imported into Unity, which made it difficult to isolate and control individual droplets within a single animation clip.

The third limitation relates to the assessment instrument. The Millikan knowledge test used in this study was originally designed by a secondary school teacher and included two questions that required prior knowledge about the evaluation methods and experimental accuracy of Millikan's original experiment. These questions were only indirectly related to the VR simulation and may have introduced a small bias in measuring the learning outcomes, as they assessed background knowledge rather than concepts directly conveyed through the virtual experiment.

Despite these limitations, the developed system provides a functional and educationally meaningful simulation of the Millikan oil-drop experiment, offering a strong foundation for further refinement and future research.

6.3 Future Work

Building upon the current implementation, several improvements could further enhance the realism, usability and educational effectiveness of the VR simulation.

A first step would be to isolate and control only the oil droplets that pass through the hole in the upper plate. This would allow the animation to respond dynamically to changes in the electric field, creating a more realistic representation of the experiment. Such refinement would also ensure that the voltage control affects only the relevant particles within the field rather than all animated droplets simultaneously.

Another enhancement would involve integrating appropriate audio feedback. Adding a subtle sound effect for the sprayer, for example, could improve sensory immersion and provide a stronger sense of interaction authenticity.

In the current setup, the oral explanation of the experiment was delivered externally by the researcher during the VR session. Future versions could integrate these instructions directly within the virtual environment, using voice narration or interactive guidance to present the information consistently and independently of external input. Likewise, the post-test could be implemented inside the VR simulation, allowing participants to complete all stages (from instruction to assessment) without leaving the virtual environment.

Another promising direction would be to extend the simulation into a multi-user environment, allowing multiple participants or an instructor and student to interact simultaneously within the same virtual laboratory. This would enable collaborative experimentation, guided instruction, and real-time discussion inside VR, reflecting the cooperative nature of real-world learning settings and expanding the potential of the simulation for group-based teaching scenarios.

Finally, the visual environment could be enriched with gentle background motion or animated elements, such as virtual avatars moving in the laboratory or a television screen displaying a looping video. These additions would make the scene appear more dynamic and lifelike, further enhancing immersion and creating a more authentic sense of presence within the simulation.

Implementing these features would not only refine the interactive fidelity of the simulation but also open new opportunities for investigating the relationship between sensory cues, realism, and learning performance in immersive physics education.

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A Questionnaires

This chapter contains the complete versions of all questionnaires used in this study. Each instrument was administered to participants as part of the data collection process described in section Study Design. The questionnaires include the Millikan Test, NASA Task Load Index (NASA-TLX), User Experience Questionnaire (UEQ), Igroup Presence Questionnaire (IPQ) and the VR Environment Questionnaire. They are presented in the order in which they were used during the experiment.

A.1 Millikan Test

1. Which objects did Millikan study in his experiment?

a) Dust particles

b) Oil droplets

c) Electrons

2. What typical properties did the oil droplets observed by Millikan have?

a) Spherical shape

b) Very high density

c) Cylindrical shape

3. Which field acted on the oil droplets, among others?

a) Gravitational field

b) Hydrodynamic field

c) Magnetic field

4. Which forces acted on the oil droplets during the different phases of the experiment?

a) Magnetic force

b) Stokes' drag force

c) Cohesion force

5. What were the directions of the forces acting on the oil droplets?

a) Stokes' drag force always acted upward.

b) The electric force always acted downward.

c) Stokes' drag force always acted opposite to the direction of motion.

6. In what ways could Millikan influence the electric field?

a) He could change the frequency of the electric field.

b) He could change the geometry of the electric field.

c) He could change the direction of the electric field.

A.2 Millikan Test

7. Which physical condition could Millikan create with his uniform-field method, among others?

a) Levitation with an electric field

b) Rising without an electric field

c) Levitation without an electric field

8. Which physical quantity could be measured directly in the experiment?

a) Droplet charge

b) Applied voltage

c) Electric field strength

9. Which physical quantity could be taken from reference tables?

a) Density of oil

b) Droplet mass

c) Droplet charge

10. Between the two methods, "falling and rising with field" is preferable to "suspending and falling without field." Why?

a) When falling without a field, there is no electric field, which is essential for evaluating the experiment.

b) In the suspension method, because of Brownian molecular motion and the associated jittery motion of the oil droplet, the suspension state is hard to measure.

c) In the suspension method, Stokes' drag force does not act, yet it is essential for evaluating the experiment.

A.3 NASA-TLX Questionnaire

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

A.4 User Experience Questionnaire

English version

obstructive	o o o o o o o	supportive
complicated	o o o o o o o	easy
inefficient	o o o o o o o	efficient
confusing	o o o o o o o	clear
boring	o o o o o o o	exciting
not interesting	o o o o o o o	interesting
conventional	o o o o o o o	inventive
usual	o o o o o o o	leading edge

German version

behindernd	o o o o o o o	unterstützend
kompliziert	o o o o o o o	einfach
ineffizient	o o o o o o o	effizient
verwirrend	o o o o o o o	übersichtlich
langweilig	o o o o o o o	spannend
uninteressant	o o o o o o o	interessant
konventionell	o o o o o o o	originell
herkömmlich	o o o o o o o	neuartig

A.5 Igroup Presence Questionnaire

Participant ID: ____________________________________ Date ____________

1. How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?

not aware at all	O	O	O	O	O	O	O	extremely aware
	-3	-2	-1	0	+1	+2	+3	
				moderately aware				

2. How real did the virtual world seem to you?

not real at all	O	O	O	O	O	O	O	completely real
	-3	-2	-1	0	+1	+2	+3	

3. I had a sense of acting in the virtual space, rather than operating something from outside.

fully disagree	O	O	O	O	O	O	O	fully agree
	-3	-2	-1	0	+1	+2	+3	

4. How much did your experience in the virtual environment seem consistent with your real world experience?

not consistent	O	O	O	O	O	O	O	very consistent
	-3	-2	-1	0	+1	+2	+3	
				moderately consistent				

5. How real did the virtual world seem to you?

about as real as an imagined world	O	O	O	O	O	O	O	indistinguishable from the real world
	-3	-2	-1	0	+1	+2	+3	

6. I did *not* feel present in the virtual space.

felt present	O	O	O	O	O	O	O	not feel present
	-3	-2	-1	0	+1	+2	+3	

7. I was *not* aware of my real environment.

fully disagree	O	O	O	O	O	O	O	fully agree
	-3	-2	-1	0	+1	+2	+3	

8. In the computer generated world, I had a sense of "being there".

fully disagree	O	O	O	O	O	O	O	fully agree
	-3	-2	-1	0	+1	+2	+3	

9. Somehow I felt that the virtual world surrounded me.

fully disagree	O	O	O	O	O	O	O	fully agree
	-3	-2	-1	0	+1	+2	+3	

A.6 Igroup Presence Questionnaire

10. I felt present in the virtual space.

fully disagree	○	○	○	○	○	○	○	fully agree
	-3	-2	-1	0	+1	+2	+3	

11. I still paid attention to the real environment.

fully disagree	○	○	○	○	○	○	○	fully agree
	-3	-2	-1	0	+1	+2	+3	

12. The virtual world seemed more realistic than the real world.

fully disagree	○	○	○	○	○	○	○	fully agree
	-3	-2	-1	0	+1	+2	+3	

13. I felt like I was just perceiving pictures.

fully disagree	○	○	○	○	○	○	○	fully agree
	-3	-2	-1	0	+1	+2	+3	

14. I was completely captivated by the virtual world.

fully disagree	○	○	○	○	○	○	○	fully agree
	-3	-2	-1	0	+1	+2	+3	

A.7 VR Environment Questionnaire

Please mark one option (1–7) for each statement.

1 = Strongly disagree 7 = Strongly agree

	1	2	3	4	5	6	7
I liked the environment.	◯	◯	◯	◯	◯	◯	◯
The environment was disruptive to my learning.	◯	◯	◯	◯	◯	◯	◯
The environment helped me settle into the learning setting.	◯	◯	◯	◯	◯	◯	◯
I would have liked more interaction with the environment.	◯	◯	◯	◯	◯	◯	◯

	1	2	3	4	5	6	7
Mir hat die Umgebung gefallen.	◯	◯	◯	◯	◯	◯	◯
Die Umgebung hat mein Lernen gestört.	◯	◯	◯	◯	◯	◯	◯
Die Umgebung hat mir geholfen, mich in die Lernsituation einzufinden.	◯	◯	◯	◯	◯	◯	◯
Ich hätte mir mehr Interaktion mit der Umgebung gewünscht.	◯	◯	◯	◯	◯	◯	◯

B Oral Explanation Script

The following script was used as the standardized verbal explanation provided to all participants before conducting the virtual Millikan oil-drop experiment. The text was delivered orally by the experimenter to ensure that all participants received the same information and instructions during the session.

> As you can see, this is the setup for the Millikan oil-drop experiment. On your right, you'll find the main chamber, which is enclosed by two white plates, one at the top and one at the bottom. The chamber itself is transparent, so you can clearly see what's happening inside.
>
> On the right side of the chamber, there's an atomizer which contains oil, and you can interact with it to spray the oil into the chamber.
>
> Inside the chamber, there are two horizontal metal plates. The upper plate has a small hole so that some oil drops can pass between the two plates. These are connected by cables to the high-voltage DC power supply on your left, which creates an electric field between them.
>
> Currently, between the two plates, two forces are acting: gravity, which pulls the oil drops downward, and air resistance (also called Stokes' drag), which acts in the opposite direction. By applying a high voltage, we create the electric field. Why do we need that? So that we can change the motion and direction of the oil drops.
>
> And why do we need that as well? Because, as you can see on the left side of the chamber, there is a gray metal cylinder with light, that's an X-ray source. It's used to ionize the oil drops.
>
> So, by applying the high voltage and creating the electric field, we can control the motion and direction of the oil drops, allowing the X-ray source enough time to charge them.
>
> Now you can aim with your right controller at the pump on the atomizer, hold it, and press to spray the oil, observe what happens without the electric field.
>
> Then, repeat the process, but this time, aim with your left controller at the knob on the power supply. After spraying the oil, press the knob and observe what happens now between the two plates.

And that is the whole Millikan oil-drop experiment, which Robert Millikan conducted in 1909. By measuring the behavior of the charged oil drops, he determined the value of the electron's charge, which is approximately 1.6×10^{-19} coulombs.

C Questionnaire Data Spreadsheets

This chapter presents the collected questionnaire data that served as the basis for the statistical analysis and result visualizations in Chapter 5. Each section below contains the aggregated responses from all participants for one of the instruments used in this study, including the pre- and post-knowledge tests, the NASA Task Load Index (NASA–TLX), the User Experience Questionnaire (UEQ), the Igroup Presence Questionnaire (IPQ) and the VR Environment Questionnaire. The data were originally recorded in Microsoft Excel and exported as tables for inclusion here to ensure full transparency and reproducibility of the reported results.

C.1 Millikan Knowledge Test Spreadsheet

Participant	Environment	Correct Answers Befor	Correct Answers After	Improvement
1	2	2	6	4
2	2	4	9	5
3	2	2	10	8
4	3	5	9	4
5	3	1	8	7
6	1	3	6	3
7	2	3	9	6
8	3	2	8	6
9	3	2	7	5
10	2	4	9	5
11	3	5	9	4
12	3	6	9	3
13	2	2	8	6
14	1	2	6	4
15	2	4	9	5
16	2	5	9	4
17	3	6	9	3
18	3	6	9	3
19	2	3	8	5
20	3	6	10	4
21	3	2	8	6
22	1	6	9	3
23	1	2	9	7
24	1	5	6	1
25	1	2	9	7
26	2	3	10	7
27	1	5	8	3
28	1	3	7	4
29	1	4	8	4
30	1	4	9	5

Low Environment Improvement	**4,1**
Medium Environment Improvement	**5,5**
High Environment Improvement	**4,5**

C.2 NASA-TLX Questionnaire Spreadsheet

Participant	Environment	Mental	Physical	Temporal	Performance (Reversed)	Effort	Frustration
1	2	30	15	15	5	20	10
2	2	20	10	10	15	10	10
3	2	20	15	15	5	10	10
4	3	35	15	15	10	25	15
5	3	35	10	20	5	10	10
6	1	25	10	25	5	15	25
7	2	15	25	15	5	25	10
8	3	50	30	10	10	20	25
9	3	35	35	5	10	20	30
10	2	50	25	5	5	15	15
11	3	25	25	5	15	15	30
12	3	40	30	15	15	15	20
13	2	20	20	10	5	25	10
14	1	5	5	20	5	15	35
15	2	5	30	25	10	15	15
16	2	10	20	10	15	5	5
17	3	25	25	15	10	10	20
18	3	25	30	5	15	15	5
19	2	30	15	10	5	20	15
20	3	15	10	20	5	15	10
21	3	30	25	5	5	5	10
22	1	15	20	5	10	15	25
23	1	10	15	15	15	10	20
24	1	15	10	20	5	20	25
25	1	35	15	5	10	15	35
26	2	15	25	15	10	5	5
27	1	30	15	15	5	10	25
28	1	35	10	10	10	10	40
29	1	5	20	5	15	15	45
30	1	5	5	5	15	20	35

Mental Room 1	18	Physical Room 1	12,5	Temporal Room 1	12,5
Mental Room 2	21,5	Physical Room 2	20	Temporal Room 2	13
Mental Room 3	31,5	Physical Room 3	23,5	Temporal Room 3	11,5

Performance Room 1	9,5	Effort Room 1	14,5	Frustration Room 1	31
Performance Room 2	8	Effort Room 2	15	Frustration Room 2	10,5
Performance Room 3	10	Effort Room 3	15	Frustration Room 3	17,5

Low Environment	**16,33333**
Medium Environment	**14,66667**
High Environment	**18,16667**

C.3 User Experience Questionnaire Spreadsheet

Participant	Environment	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8
1	2	3	2	2	2	3	3	3	3
2	2	2	1	2	2	3	2	3	2
3	2	3	3	3	1	2	3	2	3
4	3	2	1	3	1	3	3	3	3
5	3	3	1	2	2	3	3	3	2
6	1	1	2	2	3	1	3	3	3
7	2	2	2	2	3	3	2	3	2
8	3	3	3	1	1	3	3	2	3
9	3	3	2	2	3	3	2	3	3
10	2	1	1	1	1	2	2	3	3
11	3	3	1	2	1	2	3	3	3
12	3	2	1	3	2	2	2	3	3
13	2	1	1	1	1	2	2	3	3
14	1	2	3	2	3	2	2	2	2
15	2	3	2	2	2	3	3	3	2
16	2	3	2	3	2	2	2	2	2
17	3	3	2	3	2	3	3	3	2
18	3	3	1	3	3	2	2	2	2
19	2	3	3	2	2	3	2	3	2
20	3	2	2	2	2	3	2	3	3
21	3	2	3	3	1	3	2	2	3
22	1	2	3	3	3	1	2	3	1
23	1	3	2	3	3	0	2	2	1
24	1	1	3	3	2	1	3	2	1
25	1	1	2	3	3	2	2	3	3
26	2	2	2	3	3	3	2	2	3
27	1	2	2	3	2	2	2	3	1
28	1	2	2	2	2	1	2	3	3
29	1	3	1	2	2	0	2	2	3
30	1	2	2	3	3	2	3	2	3

C.4 Igroup Presence Questionnaire Spreadsheet

Participant	Environment	1.Qs	2.Qs	3.Qs	4.Qs	5.QS	6.Qs	7.Qs	8.Qs	9.Qs	10.Qs	11.Qs	12.Qs	13.Qs	14.Qs
1	2	-1	3	0	1	2	1	1	1	-1	1	1	-1	2	2
2	2	1	2	2	0	1	-1	1	2	1	2	0	0	3	1
3	2	0	2	2	3	-2	-2	1	2	1	2	-1	-1	3	1
4	3	0	2	-2	2	2	0	3	3	3	3	-3	2	3	3
5	3	0	2	2	1	2	0	3	1	2	2	-3	-1	3	2
6	1	-2	2	-2	3	1	0	3	2	3	0	-1	-3	2	2
7	2	-1	3	0	2	0	0	1	2	1	2	-1	0	3	3
8	3	0	0	1	0	1	1	3	2	2	2	-3	-2	1	0
9	3	0	3	-1	2	0	2	3	1	1	-2	-3	-1	3	0
10	2	-1	3	2	2	3	-2	-1	2	-1	2	1	1	2	2
11	3	-2	2	0	-1	0	1	2	1	1	1	1	0	3	1
12	3	-2	2	0	1	1	2	2	1	0	0	1	-3	2	1
13	2	0	3	1	2	1	0	-2	2	1	1	1	-1	2	2
14	1	-2	1	-2	1	1	-3	1	2	2	1	-2	1	1	1
15	2	1	1	2	2	1	-1	-2	2	2	2	2	-1	2	2
16	2	1	2	1	0	0	-1	1	1	2	1	0	1	2	0
17	3	-1	-1	3	2	0	-2	3	3	3	2	-1	-3	3	1
18	3	-2	2	2	1	3	-3	2	3	3	3	-2	0	3	2
19	2	2	3	2	2	-1	-2	-2	2	1	1	2	-1	1	-1
20	3	-2	3	-2	3	2	-2	3	2	0	2	-1	0	3	2
21	3	-2	2	1	1	1	-2	2	1	3	2	-2	-1	3	2
22	1	0	-1	1	0	-1	0	1	1	2	1	-1	-1	1	-2
23	1	-2	2	1	0	-2	-2	1	2	2	2	1	-1	3	0
24	1	2	1	2	3	1	-1	-3	1	2	1	-1	-1	3	0
25	1	2	1	0	2	1	0	1	0	1	1	1	2	1	0
26	2	2	3	3	3	3	-3	2	3	3	3	-2	0	3	3
27	1	1	2	1	2	0	-2	1	1	2	1	0	-1	2	-1
28	1	2	1	1	1	-1	-1	-2	0	2	1	-1	-1	2	0
29	1	1	1	2	2	-2	-2	-1	0	1	2	0	-2	1	-1
30	1	-2	1	1	0	-1	0	1	1	2	2	-1	-2	2	0

	Low Environment	Medium Environment	High Environment
General Presence	1,00	1,90	1,80
Spatial Presence	0,66	0,83	1,09
Involvment	-0,30	0,90	0,90
Experienced Realism	0,33	1,18	0,80

	Mean
Low Environment	0,42
Medium Environment	1,20
High Environment	1,15

C.5 VR Environment Questionnaire Spreadsheet

Participant	Environment	Liked	Not Disruptive	Helped Settle	More Interaction
1	2	70	30	70	50
2	2	60	30	70	50
3	2	50	30	60	40
4	3	70	50	60	50
5	3	60	70	60	30
6	1	30	50	40	50
7	2	60	50	30	20
8	3	60	60	50	40
9	3	70	60	60	50
10	2	60	50	70	30
11	3	70	60	60	40
12	3	70	60	70	50
13	2	60	60	60	30
14	1	50	70	40	20
15	2	70	20	60	30
16	2	60	20	70	40
17	3	60	50	60	30
18	3	70	60	50	20
19	2	70	20	50	20
20	3	70	60	60	70
21	3	60	50	40	70
22	1	50	30	40	30
23	1	30	70	50	20
24	1	20	50	30	30
25	1	40	40	50	30
26	2	70	50	60	40
27	1	30	20	40	30
28	1	50	20	30	20
29	1	40	30	50	20
30	1	30	40	30	30

liked Low Environment	37
liked Medium Environment	63
liked High Environment	66

More Interaction Low Environment	28
More Interaction Medium Environment	35
More Interaction High Environment	45

Helped Settle Low Environment	40
Helped Settle Medium Environment	60
Helped Settle High Environment	57

Undsruptive Low Environment	58
Undisruptive Medium Environment	64
Undisruptive High Environment	42

Overall Satisfaction	
Low Environment	**40,75**
Medium Environment	**55,5**
High Environment	**52,5**