Student Perceptions of VR Labs Modeled after Traditional Physical Labs in Non-Destructive Measurement Testing

Raymond Leonardo Chandra*, Djamel Berkaoui, Patrick Querl, Koen Castermans, and Heribert Nacken

Academic and Research Department Engineering Hydrology, RWTH Aachen University, Aachen, Germany
Email: chandra@lfi.rwth-aachen.de (R.L.C.); berkaoui@lfi.rwth-aachen.de (D.B.); querl@lfi.rwth-aachen.de (P.Q.); castermans@lfi.rwth-aachen.de (K.C.); nacken@lfi.rwth-aachen.de (H.N.)
*Corresponding author
Manuscript received September 17, 2024; revised October 21, 2024; accepted November 15, 2024; published March 12, 2025

***Abstract*—This study assesses how the student perceives the use of virtual reality labs to perform the non-destructive measurement testing in comparison to physical labs. The research involved 35 mechanical engineering student who used digital caliper, ultrasonic sensors, optical lenses and 3D scanner in both Virtual Reality (VR) and physical lab setting. Results from self-assessment surveys indicated no significant differences between the groups which suggest that the order of lab experiences did not impact the student's perception of the VR lab. However, prior experience with physical labs seems to enhanced comprehension and VR lab's perceived value, with average ratings increasing from 3.7 to 4.1 on a 5-point scale. Despite this, students rated VR labs poorly for hands-on coordination training (μ: 3.2), indicating that skills learned in VR were not fully applicable to physical labs. In order to improve practical skill transfer, future research should concentrate on enhancing VR realism, expanding sample sizes, and investigating the long-term effects of VR training.**

***Keywords*—Virtual Reality (VR), education, non-destructive testing, physical labs, VR lab**

I. Introduction

The use of digital technology in the teaching and learning field is becoming more widespread [1]. Scholars have explored the potential of using various emerging technologies in higher education, including mobile devices [2], video lecture platforms [3], augmented reality education, and also Virtual Reality (VR) [4, 5], which enables lecturers to deliver teaching content in various ways. Due to continuous technological advancements and the immersive nature of VR, universities have begun to widely adopt the technology [6]. The term immersion is used to describe the sensation of being fully present in a virtual world which often leads to a sense of detachment from reality and a perception of physical presence within the non-physical world [7]. Additionally, studies [8, 9] have shown that the use of VR has resulted in increased motivation and engagement among students in which as a result they are able to retain more information and apply what they have learned more effectively after participating in VR exercises [5].

One common use of VR in higher education is through VR labs which can serve as digital replicas of actual or partially physical labs [10]. Virtual labs have been previously implemented in various fields such as chemistry labs [10], automotive training [11] and even medical applications [12]. These studies use VR labs as supplements to traditional laboratories, particularly in visualizing abstract concepts and processes that are difficult to grasp solely through conventional methods. Some studies utilize virtual labs for safety training to address potential hazards in physical labs that may arise while performing tasks [13]. Other studies evaluate the effectiveness of VR in developing training modules for mechanical engineering students [14]. The pilot testing shows that those who used VR first scored significantly higher on subject matter tests [14]. Another purpose of using VR in lab scenarios is the limited access to modern equipment to do practical courses in engineering studies [15]. The results suggest that VR training improves student skills and comprehension of practical topics [15].

Despite significant findings on VR's benefits, there is still limited understanding of how students perceive the efficiency of VR labs compared to traditional physical labs in measurement techniques [14]. In this field, users' knowledge and proficiency in handling measurement equipment are necessary [16]. Therefore, it is important to understand how motivated they are during learning and their perceptions of using VR versus traditional physical labs [17]. These factors are important in determining whether VR is a suitable tool to learn measurement techniques [17]. Thus, to better evaluate the student's perception of the VR measurement lab, further tests are deemed as a requirement.

This study aims to assess student self-perceptions regarding the use of VR labs modeled after traditional physical labs for non-destructive measurement testing. Additionally, we seek to investigate whether the order in which students experience the labs affects their self-assessment ratings. We report the rating given by the students when using VR in four non-destructive digitized laboratory settings with different measurement tools which were: a digital caliper, an ultrasonic sensor, optical lens components, and a 3D-scanner. These tools were selected for this experiment because they were the most commonly used by students from mechanical engineering studies during their practical courses. The digitalization of the measurement labs was motivated by the need of international students that were required to come to Germany to do an excursion, but were unable to do so due to the global Corona pandemic. Hence, to make the excursion courses more resistant to external influences such as pandemics, geographical or other unexpected circumstances, the virtual laboratories were implemented.

To address the difficulties associated with developing such a measurement lab in VR, we employ the use of the MyScore software [18, 19] due to the software being open-source in nature and offering broad platform support to foster the reproducibility of our results. The study was conducted with mechanical engineering students from German University of Technology, Oman (GUtech) who were the target group that was required to do an excursion at the RWTH Aachen University, Germany. During the experiment, students were required to do specific tasks that were associated with the physical lab as well as the VR measurement lab.

II. Literature Review

The concept of virtual lab is not entirely new and has been implemented in various fields. A study presents a VR Lab that provides college students with a safe learning complex to study how the silicon wafers are being processed [11]. The study involved 14 students who showed positive learning effects and increased confidence. They reported that the VR technology is a complementary approach during situations like the pandemic. Other researchers also investigate the VR chemical laboratory as a medium to demonstrate chemical concepts which explore molecular structures [10]. Seventy students who participated in this chemistry study activity have shown significant learning gains. VR lab's advantages have also been investigated in the medical school [12]. The students participate in a voluntary VR-based teaching session as part of their emergency medicine course. The result showed a strong positive attitude toward VR-based teaching and assessment, though positivity was lower among female students which indicated a need to address gender differences. However, confidence in the medical content was low which hinted at the need for additional training in emergency medicine. Another study was also conducted to review fire safety training [13]. They analyzed data from 52 papers and found that VR training outperformed traditional methods in knowledge acquisition. A study comparing VR and AR training modules for mechanical engineering labs showed that 118 participants who engaged in VR activities first scored higher on subject matter tests than those who did physical activities first [14]. Moreover, 53 students also tested VR labs in comparisons to physical labs to conduct biology experiments [20]. The participants reported that VR was a motivating way to learn a new biology topic [20]. Another researcher compares VR labs and physical labs in the engineering education [21]. They found out that participants suggest to utilize VR labs first before engaging in physical labs [21].

In this paper, we evaluate students' self-perceptions and opinions on using VR labs compared to physical labs for non-destructive measurement testing. Additionally, we investigate whether the order in which students experience each type of lab affects their self-perception. These resulting data from this experiment can complement and enhance the finding of previous research. Furthermore, our open-source software approach, allow other researchers to used our VR labs to reproduce the experiment.

III. Materials and Methods

In this chapter, we outline the hardware used and the concept of both physical and VR measurement labs. It details specific devices such as the Meta Quest 3 VR headset, MarCal 16ER digital caliper, Olympus OmniScan MX2 ultrasonic sensor, optical lens components, and ATOS Core 200 3D scanner. The chapter also explains how the virtual labs were modeled to resemble the real physical labs. Additionally, this chapter also describes the tasks that students performed in both environments to assess their comprehension and skills.

A. Hardware

We used the Meta Quest 3 VR headset for the virtual lab practice because of the device being a standalone device and arguably easy to handle, which reduces the setup complexity. The Meta Quest 3 were developed by Meta Inc [22]. The VR headset has a resolution of 2,064 x 2,208 pixels per eye with a refresh rate of up to 120 Hz. The user interacts with the virtual object via two hand-held controllers that employ six degrees of freedom tracking. Additionally, Meta Quest 3 supports Room-Scale VR that allows users to freely move around within a designated area.

B. Physical Lab and VR Measurement Lab Concept

In this study, we compared the four measurement labs in both physical and virtual environments. The virtual measurement labs were modeled after the physical labs as closely as possible. The four virtual labs were designed to be positioned within a virtual space in such a way that multiple students can simultaneously and collaboratively conduct the labs in VR without significant time interruptions.

1) Digital caliper

The measurement device used in this experiment was the MarCal 16ER digital caliper. The caliper is a precision instrument used in measuring the dimensions of objects. It mainly uses a primary scale and a sliding jaw with a screen to indicate the measurements in various units. It has a digital type of display whereby a user can easily read the measurement values. The digital caliper in the physical lab was connected to a computer which ran the measurement program, namely, Destra Q-DAS, which automatically recorded the measurements when the student pressed the record button on the caliper [23]. In this experiment, the caliper was used to measure a metal cylindrical hollow experimental object (diameter of 20mm).

The VR counterparts were also designed to match with the physical lab version. For the virtual version, a 3D model of the digital caliper and a simulated environment modeled after the Destra Q-DAS measurement program was created, along with experimental objects. To simulate human error that can happen in real life, a randomizer which introduced slight variations (± 0.15mm) in the measurement was also developed. To achieve better handling in VR, the sizes of the experimental object and the caliper were scaled about 2 times larger than in the physical lab. The user can measure the virtual cylinder by pressing the trigger button on the VR controller with varying pressure, which moves the caliper's measuring jaws accordingly. The caliper's jaws then detect contact with the cylindrical object through collision detection. Once contact is made, the measurement is displayed on the virtual screen which providing immediate feedback to the user. A screenshot of the physical caliper and Destra Q-DAS program including its VR counterpart can be seen in Fig. 1 and Fig. 2.

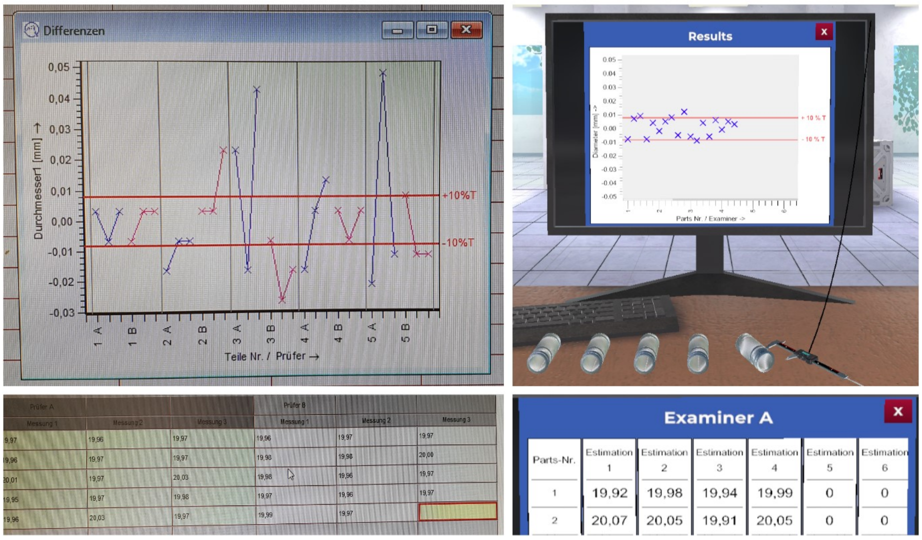

Fig. 1. Destra Q-DAS program's screenshot and the VR measurement setup.

Fig. 2. The MarCal 16ER digital caliper and the VR counterpart.

1) *Ultrasonic measurement sensor*

The device used and digitized for physical experiment was the Olympus OmniScan MX2 (Fig. 3), developed by Olympus IMS. The device employs the use of an ultrasonic testing method which is a non-destructive technique that was used to measure material thickness and detect internal flaws.

Fig. 3. The Olympus OmniScan MX2 ultrasonic device and the VR counterpart.

The ultrasonic device consists of two main components: a control panel and an ultrasonic probe. The control panel allows users to adjust the frequency, calibrate the sensor and convert sound waves into images or frequency data. An ultrasonic probe emits high-frequency sound waves into the material. These waves travel through the material and reflect back upon encountering an obstacle, namely a flaw. The time it takes for these echoes to return is recorded. The formula for the thickness detection is calculated as;

$$x = \frac{t_x \cdot c_{material}}{2}$$

where x denotes the depth of the flaw, tx is the time it takes for the ultrasonic pulse to travel to the flaw and back to the probe and c_{material} is a known constant dependent on the individual material. By measuring the time and knowing the material's constant, the depth x can be calculated. A graphical representation of the received echoes then is shown in the control panel monitor.

The VR counterparts were simplified to a monitor that displays the frequency of the virtual probe, as shown in Fig. 3. We chose to make the monitor larger than the physical lab counterpart to achieve better visibility in reading small text in VR. The ultrasonic probes were designed in a similar size and able to simulate a frequency transmission just like in real probes. Similar to the physical ultrasonic sensor, students can freely manipulate the virtual ultrasonic probe to measure different points on a test object's surface without being restricted to a specific area. The frequency was then visualized on the VR monitor which mapped the depth of the flaw that was detected.

2) *Optical lens components*

The optical lenses used in this experiment can detect defects on a sheet of Carbon Fiber Reinforced Polymer (CFRP). The physical lab components and its VR counterpart can be seen in Fig. 4.

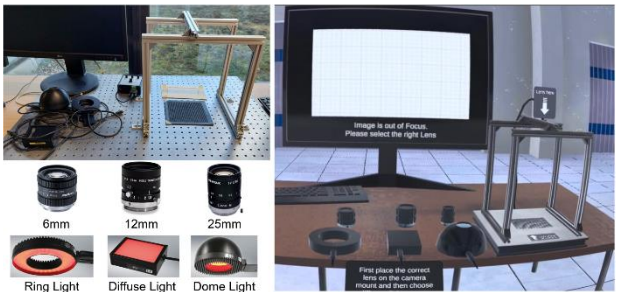

Fig. 4. The optical sensor experiment setup and its VR counterpart.

The optical sensor setup consists of a monitor, a steel frame structure to hold a lens, three types of camera lenses with focal lengths of 6mm, 12mm and 25mm and three types of light sources which are ring, diffuse and dome light. The combinations of different lenses and light sources can either help or make the flaw detection more difficult. For example, if the student chooses a lens with an unsuitable focal length, the image transmitted to the monitor will be blurry, which will be difficult to see seam, tear or cavities in the CFRP sheet.

The optical sensor VR experiment also replicates the fundamental physical lab optic concept functionality. In VR, students can attach one out of three different lenses to the steel frame and use one out of three distinct light sources on the prepared CFRP sheet. Just like in the physical lab experiment, if a student chooses the wrong lens, analyzing the virtual CFRP sheet will be made more difficult due to a blurry image displayed in the virtual monitor. Similarly, using different light sources can make it easier to analyze errors in the sample sheet. With this experiment, the students were expected to gain an understanding of using a lens with the right focal length in combination with using different light sources for error analysis.

3) 3D scanner

In this study, we employed the use of ATOS Core 200 which is a 3D scanner used for the three-dimensional measurement of small and medium-sized objects [24]. The 3D scanner is equipped with stereo 5-megapixel camera technology that features a Charge-Coupled Device camera that converts light into electronic signals using an array of light-sensitive pixels. The maximum scanning measurement area is 20 x 15 cm. The 3D scanner is based on so-called blue light technology and works with narrow-band blue light which can filter out the unwanted ambient light during image acquisition which leads to higher and precise object scanning [22]. Fig. 5 displays the ATOS 3D scanner along with its VR counterpart.

Fig. 5. ATOS 3D scanner and its digitized version in VR.

The VR counterpart was a simplified version of the 3D scanner and only had the core functionality, which was scanning an object. Some features like how the plate was attached to the scanning plate were omitted to prioritize teaching the fundamental concept of 3D scanning. However, the VR counterpart could scan the given object, display the scanning process, and allow the student to rotate the 3D scanner plate and flip the object which mimics the step that the student needs to do in the scanning process just like in a physical lab. In this study, the object used for scanning was a rectangular plastic plate with an extruded word "gom" written on it. The scanned object was referred to as a gom object in this paper

C. Participants

There were a total of 35 students from the mechanical engineering course, with 21 male and 14 female participants. Although the experiment was conducted in Germany, all of the participants came from the GUtech (German University of Technology in Oman) as part of an excursion with the partner university that occurs annually. The participants' levels of VR familiarity varied. 11 participants occasionally interacted with VR, usually in technology trade shows. 21 participants had heard of VR and were aware of its concept, but had never actually used it before. Two participants claimed that they used VR on a regular basis for personal use, either socializing or for entertainment. One participant was not aware of VR prior to this study.

D. Experiment Procedure

In this chapter, we outline the steps involved in the study experiment. Students were divided into two groups, each required to complete both physical and virtual labs in alternating order. We provide a detailed explanation of their tasks, which included measuring objects with calipers, using ultrasonic probes, evaluating CFRP sheets with optical lenses, and conducting 3D scanning in both physical and VR environments. Additionally, we present the results from student surveys that rated their VR lab experiences on a Likert scale to assess the acceptance of VR technology as an educational tool.

1) Pre-experiment preparation

The students were assigned specific tasks in both the physical and virtual versions of each lab. Prior to the experiment, both groups received a basic introduction about each of the four physical labs by a lecturer via a slide presentation. The presentation covered the basic experiment procedures, equipment involved, and safety protocols for each lab. A separate introduction to the use of virtual reality headsets was conducted before the students could use the virtual labs. Students were then randomly divided into group A and group B to reduce bias. There were 20 students in group A who first conducted the VR lab measurement experiment. On the opposite, group B, composed of 15 students that started with the physical lab experiment before transitioning to the VR measurement lab. Both the physical and VR labs began with the measurement labs, followed by the ultrasonic lab. Next, the students did the optical lens component, and finally, the labs concluded with 3D scanning. Afterwards, the groups switched tasks. The group that initially conducted the physical lab performed the experiment in VR, while the group that started with the VR lab moved on with the physical lab.

In both the physical and VR labs, a supervisor was present to observe the students during the experiments. Before starting the VR experiment, a general learning exercise was given to the participants with different levels of VR familiarity by a supervisor. This exercise involved how to move and interact with objects within the virtual environment. The exercise was conducted to ensure students could use the VR hardware effectively to minimize immersion breaks. Once students felt confident, they proceeded with the VR experiment independently. Students could repeat and practice the VR experiments as many times as desired, while physical lab experiments were limited due to labor time constraints. Throughout all experiments, a supervisor was available in both physical and VR labs to oversee progress and provide guidance when needed.

2) Physical and VR experiment phase

The first lab was about object measurement using digital calipers. Students were introduced on how to properly use the digital caliper and recording software (Destra Q-Des). In the physical lab, they were given the task to measure the diameter of five different hollow cylindrical objects using the caliper. Every 20 measurements they change to another hollow cylindrical object and repeat the process until they reach 100 measurements. The results were recorded in the Destra Q-

DAS pre-configured software. Similar tasks were given to the student in the virtual lab just like they did in the physical lab. In the VR lab, students use a virtual digital caliper to measure virtual cylindrical objects. Via a press of a button on the VR controller the measurements were recorded and can be viewed on the virtual monitor.

The second lab focused on ultrasonic measurement. Students received a technical introduction to the ultrasonic device and preparation steps, including setting up the object, water, and device. In both the physical and virtual lab, it was required to use the ultrasonic probe to identify the thickness between the drill holes of the given metal block by observing and understanding the feedback frequency on a screen. Additionally, they needed to measure the depth of the holes inside the metal block.

The third lab involved optical lens testing, where students evaluated a prepared CFRP sheet using various optical lenses and light sources. They needed to determine which lenses (6/12/25 mm focal lengths) needed to be mounted to a camera holder. Moreover, they needed to experiment with ring, diffuse, or dome lighting to determine the best combination for evaluating flaws in the CFRP sheet. The VR lab followed the same procedure, allowing students to experiment with the combination of virtual lenses and lighting sources to assess the quality of the virtual CFRP sheet.

The fourth lab was the 3D scanning experiment. Students received an overview of the 3D scanner and software setup. In the physical lab, they fixed a gom training object in the scanner, rotated the scanning plate, flipped the object to scan the object's backside, and examined the scanned object from multiple angles to ensure full coverage. They then viewed and assessed the scanned object on the screen as a 3D model. The VR lab followed the procedure that happened in the physical lab. The students needed to scan the gom object and ensured that the object was fully scanned. They did this by rotating the virtual plate on the 3D scanner and clicking a "scan" button in VR.

As a summary, this section has documented the hardware, lab concepts, participant details, and experimental procedures used in our study. By providing a transparent and reproducible methodology, the foundation to compare student perceptions between VR and traditional physical labs has been established. These methods will help us assess student self-perceptions regarding the use of VR labs modeled after traditional physical labs for non-destructive measurement testing. Furthermore, the detailed stages of the experiment ensure that our methodology is reproducible and can be further investigated by other researchers.

IV. Result and Discussion

Following the measurement experiments in the physical and virtual labs, students rated their VR lab experiences on a Likert scale ranging from 1 to 5 (1 being the lowest and 5 the highest) by participating in surveys. The results are displayed in Table 1. The survey included five questions asked to the students, which were:

1) Can the virtual lab serve as an introductory point prior to the actual lab?
2) Do activities in the virtual lab help understand and learn actual experiments?
3) Do the virtual lab train hands-on coordination skills compare to traditional labs?
4) Does the virtual lab improve motivation to learn?
5) What is the overall perception of the Virtual Labs?

This gathered feedback aims to provide evidence of students' acceptance of VR technology and its efficacy as a learning tool in educational contexts.

The gathered data were analyzed via the use of descriptive statistics in combination with a Mann-Whitney U test. Due to the test being a non-parametric test, the Mann-Whitney U test does not rely on any assumptions about data distribution which makes it well-suited for data like self-assessment ratings [25]. In addition, the test was also ideal for ordinal data, such as the Likert scale scores which were used in this experiment [25]. Afterwards, the general student feedback, including the perceived advantages and disadvantages of the VR measurement lab, was presented. The data were initially analyzed for each group's ratings, then combined. Finally, we checked for significant results based on whether the participants experienced VR labs or physical labs first.

In general, the test revealed that the order of experiencing the virtual versus the real lab does not significantly influence the rating of any experiment in the five questions that were analyzed in the study. Thus, only the responses from group A and B combined are depicted in Fig. 6–10.

Table 1. Student's assessment result

Group A (VR Lab and then Physical Lab)																						
No	**Familiarity**	**sex**	**Q1. The virtual lab can be used to serve as an introductory point prior to the actual lab**				**Q2. The activities in the virtual lab help to understand and learn the actual**				**Q3. The virtual lab trains the hands-on coordination skills compared to traditional .**				**Q4. The virtual lab improves my motivation to learn**				**Q5. Overall I like the virtual lab**			
			C	**U**	**L**	**S**	**C**	**U**	**L**	**S**	**C**	**U**	**L**	**S**	**C**	**U**	**L**	**S**	**C**	**U**	**L**	**S**
1	3	m	5	5	5	5	2	5	5	1	3	3	3	4	5	5	5	5	5	5	3	4
2	2	f	4	2	5	5	5	2	5	4	3	4	3	2	4	5	5	5	4	1	5	5
3	3	m	1	2	4	1	3	2	1	2	1	2	1	1	2	3	3	2	2	2	2	2
4	2	m	5	4	5	5	5	4	4	5	3	2	3	3	3	5	5	5	5	5	4	3
5	3	f	5	5	5	5	5	4	5	4	2	5	2	2	5	5	4	2	5	5	2	5
6	3	f	5	4	4	5	4	5	5	3	1	3	2	3	5	3	2	3	5	5	5	5
7	3	f	3	3	4	3	4	4	4	4	4	5	4	5	5	3	5	5	4	5	5	4
8	2	f	4	5	5	5	3	4	5	3	2	3	2	3	2	3	2	2	5	5	5	5

9	2	m	1	2	2	1	3	3	4	5	3	5	4	5	3	4	5	5	2	5	5	5
10	4	m	4	5	4	5	2	3	2	4	3	2	1	5	4	5	3	3	4	5	5	4
11	2	m	4	5	3	3	3	3	4	3	4	3	5	5	4	3	5	5	1	5	5	1
12	2	m	5	3	5	4	4	5	5	5	2	3	4	3	5	4	5	5	5	5	5	3
13	2	m	2	3	2	3	2	2	2	3	5	5	3	4	3	5	2	5	5	5	5	5
14	2	m	5	5	1	5	5	3	4	4	3	3	1	1	3	4	4	3	5	5	5	5
15	2	f	4	4	3	5	3	5	5	4	5	3	3	1	5	4	3	5	4	5	1	5
16	2	m	3	4	4	5	4	4	3	5	2	3	3	2	3	5	5	2	5	1	5	5
17	3	m	5	3	5	4	2	3	3	3	3	5	3	2	3	4	5	4	5	3	5	4
18	2	f	5	3	3	4	5	4	5	3	2	5	4	3	5	3	3	5	2	5	5	3
19	2	m	5	5	5	4	5	4	3	3	5	3	4	5	4	5	5	4	5	3	5	5
20	1	f	4	4	4	4	5	5	2	5	3	1	4	3	5	2	3	5	5	5	5	5
	Average		4.0	3.8	3.9	4.1	3.7	3.7	3.8	3.7	3.0	3.4	3.0	3.1	3.9	4.0	4.0	4.0	4.2	4.3	4.4	4.2
Group B (Physical Lab and then VR Lab)																						
1	3	m	5	5	5	5	5	5	5	5	1	4	2	4	4	5	5	3	4	5	5	4
2	2	f	3	2	4	3	2	3	4	5	3	3	3	3	1	4	4	4	2	5	5	5
3	3	m	5	5	5	5	5	5	4	4.5	5	5	5	4.5	4	5	5	5	5	5	5	5
4	2	m	5	5	5	4	3	5	3	3	4	4	2	2	3	5	5	4	4	5	4	3
5	3	f	3	4	2	4	2	3	2	4	3	2	1	3	3	3	3	3	2	4	1	4
6	3	f	5	4	5	3	5	4	5	5	3	3	3	3	4	4	4	4	5	5	5	5
7	3	f	4	2	3	4	4	4	3	4	4	3	3	4	5	4	4	4	4	4	4	4
8	2	f	4	5	3	4	4	5	5	5	3	2	3	3	3	4	5	3	3	5	5	5
9	2	m	3	2	4	2	3	5	3	4	4	5	4	3	4	5	4	3	3	5	3	2
10	4	m	4	3	4	4	4	5	4	4	3	3	3	2	3	3	5	4	3	3	4	3
11	2	m	2	3	5	4	5	3	5	4	3	3	1	2	5	3	5	5	2	3	5	5
12	2	m	5	5	5	5	5	4	4	3	4	5	4	4	5	4	5	5	4	4	4	5
13	2	m	4	5	3	5	4	3	5	3	4	4	3	5	5	5	4	5	3	3	4	3
14	2	m	4	4	4	5	5	4	5	5	4	5	4	3	5	4	4	4	5	3	5	4
15	2	f	5	5	3	4	4	3	4	4	3	5	5	5	4	3	3	5	4	5	5	3
	Average		4.1	3.9	4.0	4.1	4.0	4.1	4.1	4.2	3.4	3.7	3.1	3.4	3.9	4.1	4.3	4.1	3.5	4.3	4.3	4.0

Note:
Familiarity: 1: Don't know what VR is, 2: have heard of VR, but never used it before, 3: rarely use VR, 4: use VR frequently
Sex: m: male, f: female
Measurement Lab: C: Caliper Lab, U: Ultrasonic Lab, L: Lens Lab, S: 3D Scanning Lab

A. VR Lab as Introductory Tool

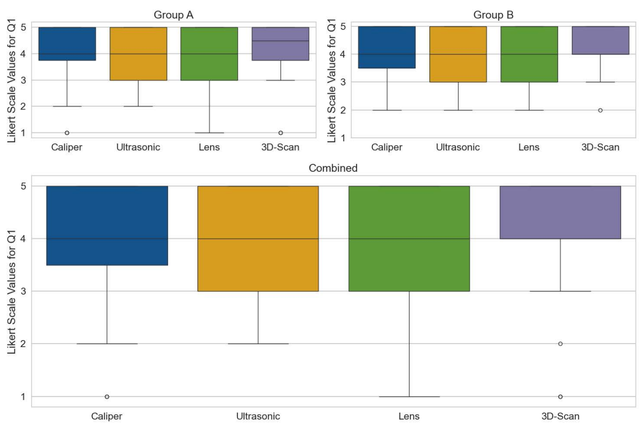

Fig. 6. Likert scale combination value of Q1.

Question 1 (Q1) from Table 1 assessed how the participants of groups A and B evaluated their experience regarding whether the virtual lab can serve as an introductory point for the real lab. The general feedback for all experiments is depicted in Fig. 6. The general trend shows that participants rated all tools relatively high (μ >=4) on average. The interquartile range (IQR) were similar across the experiment which suggest a comparable variability in responses. This suggests that all four measurement tools were generally well-received by the students.

The Mann-Whitney U test for question 1 has the following results: Caliper (p = 0.9, U = 152.5), Ultrasonic (p = 0.7, U = 137.5), Lens method (p = 1.0, U = 148.0), and 3D Scanning method (p = 0.6, U = 163.5). This indicates that the students perceive the VR lab similarly when done before or after the real-life lab. Although no statistically significant difference between the groups can be observed, group B, who did the practical lab first and then VR, overall exhibited a slightly higher average assessment rating in every measurement lab, except the 3D scanning lab, than group A.

Group A's and group B's mean ratings were as follows: Caliper Lab (μ = 4.0 vs. μ = 4.1), Ultrasonic Lab (μ = 3.8 vs. μ = 3.9), Lens Lab (μ = 3.9 vs. μ = 3.4), and 3D Scanner Lab (μ = 4.1 for both group). This might hint that having prior experience with the physical lab procedures allows students to better understand the VR lab's practical applications which enhances its perceived value as a preparatory tool. Furthermore, these results align with the review which found that VR enhances theoretical understanding but may fall short in developing practical skills due to lack of tactile feedback [4]. However, while these findings seem to show that VR labs and real-life labs were comparable and that the VR lab can serve as an introductory tool, the lack of demographic data and small sample sizes limit the confidence in this conclusion.

B. VR Lab as Learning Platform

Question 2 examines the rating given by the participants from groups A and B on how effective the VR lab was in aiding their understanding and learning of the actual experiment. Fig. 7 shows that the combined responses from both group A and group B have medians of 4 for all experiments which show positive feedback. Similar interquartile ranges indicate consistent variability. Notably, no outliers were present which shows that participants gave a uniform range of responses. The general trend shows that participants rated all tools relatively high ($\mu >= 4$) on average. In summary, most of the participants indicate that the four VR experiments can aid them in understanding and learning the actual experiment.

The Mann-Whitney U tests showed no significant differences between the groups order, with the following p-values and U-statistics: Caliper ($p = 0.5$, $U = 129$), Ultrasonic ($p = 0.3$, $U = 121.5$), Lens ($p = 0.7$, $U = 137.5$), and 3D Scanning ($p = 0.2$, $U = 109$). This suggests that students view the VR lab similarly, regardless of whether it is completed before or after the real-life lab.

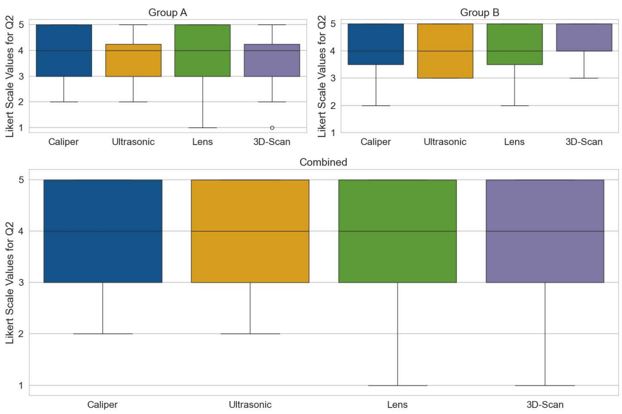

Fig. 7. Likert scale combination value of Q2.

The mean ratings for group A and group B were: Caliper Lab ($\mu = 3.7$ vs. $\mu = 4.0$), Ultrasonic Lab ($\mu = 3.7$ vs. $\mu = 4.1$), Lens Lab ($\mu = 3.8$ vs. $\mu = 4.1$), and 3D Scanner Lab ($\mu = 3.7$ vs. $\mu = 4.2$). Despite the non-significant p-values of the experiencing order, group B consistently gave a higher average rating than group A. Although, higher ratings from Group B could be due to prior experience with the physical lab, which provides a tangible understanding of the experiments and makes it easier to relate the VR lab to real-world tasks. This hands-on experience seems to raise student's confidence which helps reinforce learning objectives. Prior studies [12, 14] also highlight the complementary nature of combining VR with physical lab experiences which support our finding. However, the small sample sizes and absence of demographic data may introduce bias to the finding. Future research should explore this sequence effect further with larger sample sizes and demographic data.

C. VR Lab to Train Hands-on Coordination Skills

Question 3 asks students to rate their experience using the VR measurement lab for training hands-on coordination skills. Fig. 8 depicts the box plot for values for Q3 which shows a combined response from group A and group B. The medians vary among the experiment: Caliper, Lens and 3D scanning experiment have a median around 3, while Ultrasonic has a higher median at 4. The IQR differs, with the Ultrasonic experiment having the largest IQR, indicating more variability in responses. Overall, the data for Q3 suggests diverse experiences among students, with Ultrasonic receiving generally higher ratings and Caliper showing the most variation in feedback.

The Mann-Whitney U tests shows an insignificant difference between the group's order, with these p-values and U-statistics: Caliper ($p = 0.1$, $U = 107.5$), Ultrasonic ($p = 0.4$, $U = 127$) Lens ($p = 0.8$, $U = 144$), and 3D Scanning ($p = 0.6$, $U = 133$).

Group B once again gave higher scores than group A for all measurement labs: Caliper Lab ($\mu = 3.0$ vs. $\mu = 3.4$), Ultrasonic Lab ($\mu = 3.4$ vs. $\mu = 3.7$), Lens Lab ($\mu = 3.0$ vs. $\mu = 3.1$), and 3D Scanner Lab ($\mu = 3.1$ vs. $\mu = 3.4$). Nevertheless, the low average scores of both groups ($\mu < 4$), may suggest that the students face difficulties in transferring the practical skills obtained in the VR lab to the real lab environment. These findings align with the literatures that indicate VR is an effective tool to transfers knowledge but it still has limitations in practical experiments [20]. Learning by doing is still deemed more effective physically than virtually [21]. Moreover, the reason for the low average rating, may be attributed to the VR environment's lack of realism and tactile feedback, which can impede the development of hands-on coordination skills. Technical limitations such as lower resolution, lag, or un-intuitive controls in the VR setup, combined with students' initial unfamiliarity with the VR interface, may also detract from the effectiveness of the training and hinder skill transfer. While it is possible that the limited sample size and diversity of participants may have contributed to these findings, future studies should prioritize addressing these limitations by including larger, more diverse samples and exploring ways to enhance the realism and usability of VR labs.

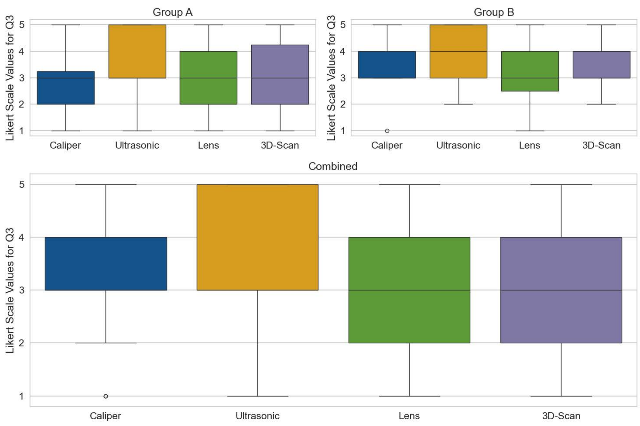

Fig. 8. Likert scale combination value of Q3.

D. General Feedback from the Students

The study comparison between physical and VR lab was well received, with 63% of students being first-time VR users. Despite initial unfamiliarity, the textual feedback from the students supported the positive impression of VR as an educational tool. However, ten students experienced motion sickness, and seventeen students reported that the VR controllers were too complex to use at the beginning.

Motion sickness is a common occurrence observed in participants during VR experiments [12]. In this study, the motion sickness experienced by the students was primarily due to their unfamiliarity with VR and the controller, as well as the need to move from one virtual lab to another. As a consequence, these students required breaks after completing one VR lab before moving on to the next. However, we did not find any correlation between motion sickness and the given ratings, suggesting that the ratings were based purely on their self-assessment.

The data from Table 1 in question 4 shows that the motivation of students from group A and B remains high when experiencing the VR lab, with ratings ($\mu \geq 4.0$) for most labs: Ultrasonic Lab (μ = 4.0 and μ = 4.1) Lens Lab (μ = 4.0 and μ = 4.3), and 3D Scanner Lab (μ = 4.0 and μ = 4.1) However the Caliper Lab received lower motivation ratings (μ = 3.9 for both groups), possibly due to the real hands and fingers movement precision required to handle the real object, which may not translate well to VR with the current controller. Some students may initially be deterred as well by an increased size of the VR caliper and measurement tool, which can be off putting to adapt to from the physical lab setting. The combined response of both groups can be seen in Fig. 9. The participants' responses were consistent, with all experiments averaging a score of 4. The similar IQR suggests that students' motivation remains enthusiastic when using the virtual lab.

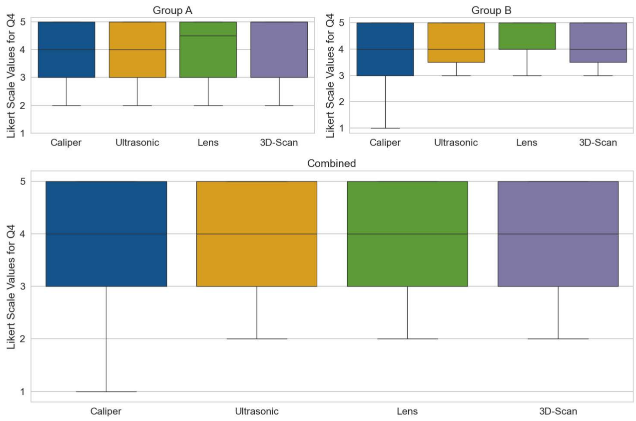

Fig. 9. Likert scale combination value of Q4.

Overall, both group A and group B shows likeliness of the virtual labs as shown in Table 1 in Q5, with mean scores ($\mu \geq$ 4.0) across various labs: Caliper Lab (μ = 4.2), Ultrasonic Lab (μ = 4.3 for both groups), Lens Lab (μ = 4.4 for Group A and μ = 4.3 for Group B), and 3D Scanner Lab (μ = 4.2 for Group A and μ = 4.0 for Group B). However, Group B rated the Caliper Lab lower (μ = 3.5), which may indicate specific difficulties with that lab. Fig. 10 shows the average combined response from both groups. All experiments were rated with an average of 4. The IQR were relatively similar, indicating comparable variability within the middle 50% of responses. However, unlike Q4, some outliers were present in the Ultrasonic and Lens methods. Despite this, participant's responses were consistent across all experiments.

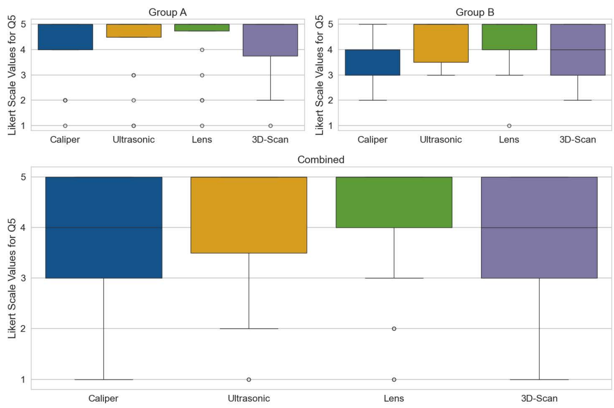

Fig. 10. Likert scale combination value of Q5.

Qualitative feedback from students further supports that the VR lab helped them better understand and visualize the experiments. It was also noted that the students' motivation was higher after experiencing the physical lab before the VR lab which solidified the finding that prior hands-on experience enhances their understanding of the VR lab. Some students from group B even noted the missing steps required in the VR Lab, such as applying a coupling medium (water) to the metal block before using the Ultrasonic probe. In addition, 26 students also reported textually that the VR Lab was preferred to be used to deepen the understanding of the lab's contents or as introducing the lab concept. Nevertheless, they noted that the VR Lab cannot fully replace the practical lab as a learning method. These student's feedback was consistent with findings from previous study [13, 20].

In conclusion, while VR labs were well-received and generally effective, addressing technical difficulties and optimizing VR for precision tasks could improve their educational value. Combining physical and VR labs in a complementary sequence might maximize student engagement and learning outcomes.

V. Conclusion and Future Work

In this study, the comparison between physical and VR measurement Lab in non-destructive measurement has been evaluated. Our experiment results showed that the order in which students experience the physical or VR lab does not really significantly affect their responses. However, the mean rating results showed that students in group B, who experienced the physical lab before the VR lab, gave higher average ratings compared to group A. This suggests that prior experience with the physical lab might help students better understand and review the VR lab. Nonetheless, both groups disagreed that the VR lab can effectively train hands-on coordination skills that were applicable to the physical lab. Qualitatively, the students particularly felt that the VR lab should be used as an introduction concept and as a tool to repeat and review the experiment. Moreover, the students believed that physical labs still remain essential for comprehensive skill development. Despite the findings, due to the small sample size in each group and the lack of diverse background, the data may introduce some bias.

Future studies should examine the long-term effect of VR training on physical lab versus VR Lab. Moreover, it will be beneficial to include students from different courses and other diversity groups as part of the experiment to exclude bias. To improve how effectively VR can be used as a VR lab, researchers should focus on replicating the physical lab features into VR. For example, instead of using controllers, they can use a dummy caliper or ultrasonic probe in which the functionality can be used in VR. In addition, instead of using controllers a hand tracking functionality can be used to improve the immersion in the VR Lab. The effectiveness of VR labs can also be compared with other preparatory tools such as video tutorials to determine if theory transfer from the physical lab can be achieved through alternative methods.

By addressing these areas, future research can provide more insights into the role of VR labs in enhancing practical skills and improving educational outcomes in engineering and other technical fields.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

RLC wrote the paper, conducted the research, analyzed the data, develop the application; DJ wrote the paper, conducted the research, analyzed the data, develop the application; PQ analyzed the data, review the paper; KC develop the 3D Graphic; HN review the paper; all authors had approved the final version.

Funding

This project has received support from "IVAC-International Virtual Academic Collaboration 2021–2022, Projekt: MeaTLOAV - Measurement Techniques Laboratory Over the Air in VR" Projekt-ID: 57599122.

Acknowledgment

The MyScore project is acknowledged to be made possible through the funding support of the German Federal Ministry of Education and Research and the German Academic Exchange Service.

References

[1] A. Berni and Y. Borgianni, "Applications of virtual reality in engineering and product design: Why, what, how, when and where," *Electronics*, vol. 9, no. 7, p. 1064, Jun. 2020. doi: 10.3390/electronics9071064

[2] L. Dias and A. Victor, "Teaching and learning with mobile devices in the 21st century digital world: Benefits and challenges," *Eur. J. Multidiscip. Stud*., vol. 5, no. 1, p. 339, May 2017. doi: 10.26417/ejms.v5i1.p339-344

[3] C. Lange and J. Costley, "Improving online video lectures: Learning challenges created by media," *Int. J. Educ. Technol. High. Educ*., vol. 17, no. 1, p. 16, Dec. 2020. doi: 10.1186/s41239-020-00190-6

[4] D. Hamilton, J. McKechnie, E. Edgerton, and C. Wilson, "Immersive virtual reality as a pedagogical tool in education: A systematic literature review of quantitative learning outcomes and experimental design," *J. Comput. Educ*., vol. 8, no. 1, pp. 1–32, Mar. 2021. doi: 10.1007/s40692-020-00169-2

[5] J. Radianti, T. A. Majchrzak, J. Fromm, and I. Wohlgenannt, "A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda," *Comput. Educ*., vol. 147, p. 103778, Apr. 2020. doi: 10.1016/j.compedu.2019.103778

[6] D. Kim and T. Im, "A systematic review of virtual reality-based education research using latent dirichlet allocation: Focus on topic modeling technique," *Mob. Inf. Syst*., vol. 2022, pp. 1–17, Aug. 2022. doi: 10.1155/2022/1201852

[7] C. R. Guerra-Tamez, "The impact of immersion through virtual reality in the learning experiences of art and design students: The mediating effect of the flow experience," *Educ. Sci*., vol. 13, no. 2, p. 185, Feb. 2023. doi: 10.3390/educsci13020185

[8] E. Krokos, C. Plaisant, and A. Varshney, "Virtual memory palaces: immersion aids recall," *Virtual Real*., vol. 23, no. 1, pp. 1–15, Mar. 2019. doi: 10.1007/s10055-018-0346-3

[9] B. Mouatt, A. E. Smith, M. L. Mellow, G. Parfitt, R. T. Smith, and T. R. Stanton, "The use of virtual reality to influence motivation, affect, enjoyment, and engagement during exercise: A scoping review," *Front. Virtual Real*., vol. 1, p. 564664, Dec. 2020. doi: 10.3389/frvir.2020.564664

[10] J. B. Ferrell *et al*., "Chemical exploration with virtual reality in organic teaching laboratories," *J. Chem. Educ*., vol. 96, no. 9, pp. 1961–1966, Sep. 2019. doi: 10.1021/acs.jchemed.9b00036

[11] X. Xu and F. Wang, "Engineering lab in immersive VR—an embodied approach to training wafer preparation," *J. Educ. Comput. Res*., vol. 60, no. 2, pp. 455–480, Apr. 2022. doi: 10.1177/07356331211036492

[12] M. Mahling, R. Wunderlich, D. Steiner, E. Gorgati, T. Festl-Wietek, and A. Herrmann-Werner, "Virtual reality for emergency medicine training in medical school: Prospective, large-cohort implementation study," *J. Med. Internet Res*., vol. 25, p. e43649, Mar. 2023. doi: 10.2196/43649

[13] D. Scorgie, Z. Feng, D. Paes, F. Parisi, T. W. Yiu, and R. Lovreglio, "Virtual reality for safety training: A systematic literature review and meta-analysis," *Saf. Sci*., vol. 171, p. 106372, Mar. 2024. doi: 10.1016/j.ssci.2023.106372

[14] A. R. Srinivasa, R. Jha, T. Ozkan, and Z. Wang, "Virtual reality and its role in improving student knowledge, self-efficacy, and attitude in the materials testing laboratory," *Int. J. Mech. Eng. Educ*., vol. 49, no. 4, pp. 382–409, Oct. 2021. doi: 10.1177/0306419019898824

[15] D. Kamińska, T. Sapiński, N. Aitken, A. D. Rocca, M. Barańska, and R. Wietsma, "Virtual reality as a new trend in mechanical and electrical engineering education," *Open Phys*., vol. 15, no. 1, pp. 936–941, Dec. 2017. doi: 10.1515/phys-2017-0114

[16] K. A. Olu-lawal, O. K. Olajiga, E. C. Ani, A. K. Adeleke, and D. J. P. Montero, "The role of precision metrology in enhancing manufacturing quality: A comprehensive review," *Eng. Sci. Technol. J*., vol. 5, no. 3, pp. 728–739, Mar. 2024. doi: 10.51594/estj.v5i3.868

[17] A. K. Ghazali, N. A. A. Aziz, K. A. Aziz, and N. T. Kian, "The usage of virtual reality in engineering education," *Cogent Educ*., vol. 11, no. 1, p. 2319441, Dec. 2024. doi: 10.1080/2331186X.2024.2319441

[18] D. Berkaoui, R. Chandra, and K. Castermans, *MyScore—Avatar-Based Teaching and Learning*, 2022. doi: 10.18420/VRAR2022_7790

[19] R. L. Chandra, D. Berkaoui, K. Castermans, and H. Nacken, "Utilizing virtual reality in higher education marketing through open-source and open-educational software," in *Proc. the 2023 7th International Conference on Big Data and Internet of Things*, Beijing China: ACM, Aug. 2023, pp. 98–102. doi: 10.1145/3617695.3617724

[20] C. Byukusenge, F. Nsanganwimana, and A. P. Tarmo, "Exploring students' perceptions of virtual and physical laboratory activities and usage in secondary schools," *Int. J. Learn. Teach. Educ. Res*., vol. 22, no. 5, pp. 437–456, May 2023. doi: 10.26803/ijlter.22.5.22

[21] L. Stuchlikova, A. Kosa, P. Benko, and P. Juhasz, "Virtual reality vs. reality in engineering education," in *Proc. 2017 15th International Conference on Emerging eLearning Technologies and Applications (ICETA)*, Stary Smokovec: IEEE, Oct. 2017, pp. 1–6. doi: 10.1109/ICETA.2017.8102533

[22] Meta Inc. (2024). *Meta Quest*. [Online]. Available: https://www.meta.com/de/en/quest/

[23] Hexagon AB. Q-DAS destra | Statistical Package. Q-DAS destra | Statistical Package. [Online]. Available: https://hexagon.com/products/q-das-destra

[24] Gom. (2020). Atos core. *Gom*. [Online]. Available: https://scanare3d.com/wp-content/uploads/2020/07/GOM_Brochure_ATOS_Core_EN.pdf

[25] S. Boslaugh, *Statistics in a Nutshell*, 2nd ed., Sebastopol, CA: O'Reilly Media, 2013.