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How Effective and Efficient Is a Virtual Lab Compared to a Remote Lab in Inquiry Learning Environment?

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Abstract

Nowadays, in STEM education, virtual and remote labs (VRLs) are used as alternatives to traditional hands-on labs to conduct experiments as a part of inquiry learning activities. At the same time, research reveal that virtual labs (i.e., simulations) have many specific advantages over remote labs (i.e., real labs that are remotely operated). In spite of the recent developments in technology, only a few studies have compared virtual labs' (VLs') and remote labs' (RLs') effectiveness and efficiency. VLs are more popular than RLs, however, there is no consensus reached regarding the comparative effectiveness of VRLs, whereas research on time-efficiency of VRLs is literally non-existent. This study investigated the effectiveness (i.e., conceptual knowledge gain) and the efficiency (i.e., time-efficiency) of VRLs in inquiry learning environment. University programme students ($n=40$) were assigned randomly to two experimental groups, of which one used a virtual lab and the other one used a remote lab. Participants followed an online lesson in physics. Students in both groups gained knowledge from pretest to posttest, hence, both labs were effective. However, no significant difference was found either in effectiveness or in efficiency between the VL and RL conditions. In addition, time spent (i.e., learning time) on a lab did not have any impact on the conceptual knowledge gain. Therefore, there is no preference of which lab to use in educational settings. Nevertheless, the results of this study point to a need to further investigate the effectiveness and the efficiency of VRLs from the design perspective.

Keywords: virtual labs, remote labs, effectiveness, time-efficiency, learning time

Table of contents

Abstract	2
Table of contents	3
Acknowledgements	4
1. Introduction	5
2. Theoretical framework	7
2.1. Remote Labs.....	7
2.2. Virtual Labs.....	8
2.3. Inquiry Learning Framework	9
2.4. Conceptual Knowledge and Concept Learning.....	11
3. Research questions and hypotheses.....	11
3.1. Conceptual knowledge gain	12
3.2. Time-efficiency	12
3.3. The effect of learning time and lab modality on conceptual knowledge gain.....	13
4. Method	14
4.1. Participants and Design	14
4.2. Instruments	15
4.3. Procedure.....	16
4.4. Data Analysis	16
5. Results	17
5.1. Conceptual knowledge gain	17
5.2. Time-efficiency	18
5.3. The effect of learning time	18
5.4. The effect of time and a lab modality.....	18
6. Discussion and Conclusion	18
References	22
Appendix A – Informed Consent	25
Appendix B – Learning Objectives	26
Appendix C – Pretest and Posttest	27
Appendix D – Quiz Overview App.....	29
Appendix E – Time Spent Summary App.....	30
Appendix F – Using Instructions.....	31

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1. Introduction

Nowadays, schools are stimulated to support students in science and engineering education. More schools use online labs such as virtual labs (i.e., simulations) and remote labs (i.e., real labs that are remotely operated) to support students. Compared to traditional hands-on labs, with virtual and remote labs (VRLs), there are fewer restrictions with regard to the number of participating students and accessibility due to a distance or due to possible learner's immobility. VRLs are advantageous over hands-on labs because they can be used from anywhere at any time and are considered to be less expensive and less hazardous (Gravier, Fayolle, Bayard, Ates & Lardon 2008).

Virtual and remote labs have particular advantages of their own, independently of each other. So, they can be used for specific purposes. To illustrate, virtual labs (VLs) support experimentation about unobservable phenomena such as thermodynamics and chemical reactions (Chiu, DeJaegher, & Chao, 2015; De Jong, Linn, & Zacharia, 2013) and can adapt reality to make interpretation of certain phenomena easier (Ford & McCormack, 2000). In addition, VLs point out salient information (De Jong et al., 2013) and allow students to apply “what if” explorations to obtain the outcomes immediately (Hennessy et al., 2007). Moreover, VLs are also an ideal tool to enable pre-laboratory preparation (Abdulwahed & Nagy, 2011; Dalgarno, Bishop, Adlong, & Bedgood, 2009) and enable learners to repeat experiments within a short amount of time (De Jong et al., 2013). Talking about remote labs (RLs), students in using RLs handle actual physical apparatus to obtain real data from physical experiments. Thus, they learn about the complexities of the real world such as dealing with measurement errors (Heradio et al., 2016). The latter makes RLs different from VLs. However, based on the Heradio et al.'s (2016) bibliometric analysis, the number of published scientific papers and citations between 1993 and 2015 is comparable with respect to VLs and RLs. This assumes that neither of the labs is better or worse and advantages of the labs need to be employed in accordance with concrete learning objectives (Heradio et al., 2016). Consequently, both lab types can be effectively used for learning.

Many studies have been conducted to assess the educational effectiveness of hands-on labs compared to VLs or RLs (e.g., Brinson, 2015; De Jong et al., 2013). Some studies tested the value of combining VRLs and hands-on labs (e.g., Abdulwahed & Nagy, 2011; Dalgarno et al., 2009; Zacharia, 2007; Wiesner & Lan 2004). Only a few studies compared the educational effectiveness of VLs to that of RLs. Corter, Nickerson, Esche and Chassapis (2004) stated that VRLs were equally effective in terms of conceptual knowledge gain in a junior level

mechanical engineering course on machine dynamics and mechanisms. Similarly, Tzafestas, Palaiologou and Alifragis (2006) who conducted a research in the field of robotics, reported that learning with VLs could be as effective as with RLs. In contrast, Lindsay and Good (2005) concluded that, in terms of learning outcomes, VRLs are not equivalent as each type has its own strengths and weaknesses. In the same line, Ma and Nickerson (2006) determined that no consensus existed regarding the comparative effectiveness of hands-on, virtual and remote science labs when they reviewed sixty articles (i.e., nearly all studies focused on outcomes related to knowledge and understanding). Brinson (2015) confirmed and extended Ma and Nickerson's results by focusing on the review of empirical studies only that compared learning outcomes between hands-on labs and VRLs. Thus, existing research focused on the effectiveness of VRLs. Nevertheless, there seems to be no robust evidence of the superiority of one of the labs (i.e., VL and RL) over the other. At the same time, research demonstrates that each of the labs is independently as effective as a hands-on lab (e.g., De Jong et al., 2013; Faulconer & Gruss, 2018). Therefore, the question of comparative effectiveness of VL and RL remains to be unanswered.

As for efficiency of VRLs the research base is literally non-existent. Indeed, the issue of efficiency of VRLs has been rather ignored or it has been only barely mentioned that virtual experiments are more time-efficient than hands-on labs (De Jong et al., 2013; Zacharia, Olympiou & Papaevripidou, 2008). However, the latter statements on efficiency have not been backed by any empirical evidence. Therefore, there is a need to extend the investigations of the comparative time-efficiency of VRLs. In addition, the current study will focus on whether increased learning time on experiments conducted in VRLs leads to increased learning outcome, similarly to findings in other domains (Kidron & Lindsay, 2014). Indeed, as an ultimate goal is knowledge gain, first, for practitioners it is essential to know to what extent an extra learning time can be justified from the learning gain perspective. Secondly, a question arises whether a lab modality is related to the effect of an extra learning time on the learning gain.

This study is a part of the Go-Lab project (<https://www.golabz.eu>), which is maintained by the University of Twente (the Netherlands) and aims to facilitate the use of innovative learning technologies in STEM education (i.e., science, technology, engineering, and mathematics), with a particular focus on online labs and inquiry learning applications. In these labs, students usually engage in inquiry learning activities as they take the role of a scientist. They ask questions, formulate hypotheses, conduct experiments, and draw conclusions. The

research might contribute to the latest developments aimed at the geographical expansion of the Go-Lab platform (e.g., inclusion of more European and African countries) and might explain why the number of VLs exceeds the number of RLs in the Go-Lab platform.

This study aims to determine how effective and efficient a virtual lab is compared to a remote lab in inquiry learning environment. The main reasons for this study are: 1) inconsistency of findings about the effectiveness (i.e., conceptual knowledge gain) of VLs compared to RLs; 2) the existing gap in the study of efficiency (i.e., time-efficiency) of VLs versus RLs and of the effect of efficiency on effectiveness; 3) rapid developments in digital environment-based technologies (e.g., microworlds and simulations), that is, the technologies enabling learners to interact with digital environments that respond to the learners actions in a dynamic mode (Mayer, 2014); and 4) an increasing interest of educational settings towards effectiveness of VRLs due to the cost pressure that are related to laboratories and a number of other reasons (Faulconer & Gruss, 2018; Ma & Nickerson, 2006). The study would enable schools, universities, and stakeholders (i.e., researchers, designers, and teachers) to make a clear decision with regard to a lab modality based on the effectiveness of VRLs.

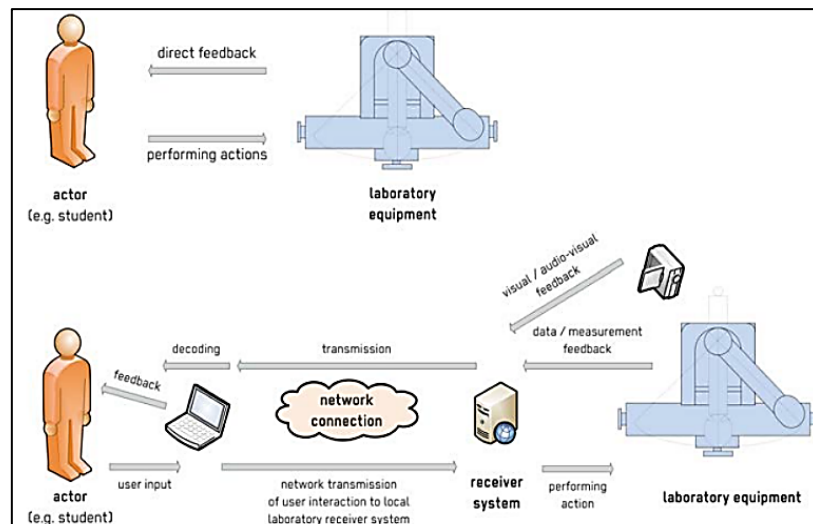
2. Theoretical framework

2.1. Remote Labs

Remote labs (RLs) enable students to carry out experiments, which are normally performed in real-time physical laboratories, over the Internet (Heradio et al., 2016; Seiler & Sell, 2013). Compared to a hands-on lab, additional equipment is needed to prepare traditional labs for online access (Seiler & Sell, 2013). As illustrated in Figure 1, a student is connected to the Internet via a personal device (e.g., a computer, a smart phone, or a tablet). The student performs by utilising specific software or just by accessing a web application running in any common web browser. The student's actions are transmitted to a receiver system and the user/laboratory management system enables access of rights and booking. The receiver system is directly connected to the laboratory equipment whereby a student performs common actions for a specific experiment using the hardware. During an experiment audio and visual equipment (e.g., a microphone and a camera) record results of the experiment. The results will be communicated back to the student via the receiver system.

Figure 1

A Hands-on Lab Versus a Remote Lab



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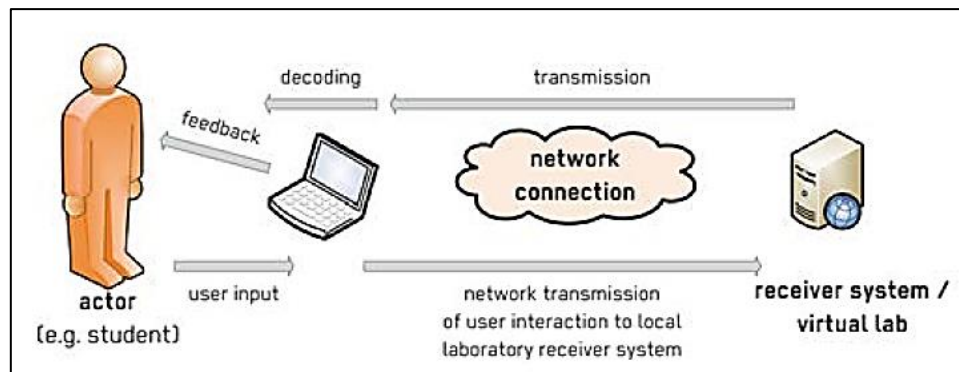
The distinguishing feature of RLs is in applying actual physical apparatus for physical experiments (Heradio et al., 2016). This replicates the routine followed in hands-on labs, therefore, students can extract real data from the physical experiments (Heradio et al., 2016). In this way, students learn about the complexity of the real world (e.g., measurement errors). However, RLs approach is complicated by the need to use an additional equipment to prepare traditional labs for the online access.

2.2. Virtual Labs

Virtual labs (VLs) simulate scientific equipment, which is used by a student via the Internet (Heradio et al., 2016), as illustrated in Figure 2. In this sense, the lab environment is replicated as the experimentation interface in a virtual system. Several students can interact simultaneously with the same virtual system. As it is a simulated process, it can be instantiated to serve anyone who asks for it (Bencomo, 2004). The common feature of all VLs is that real experiments are virtualised or simulated in software or app, in most cases dealing with a challenge being close to reality (Seiler & Sell, 2013).

Figure 2

A Virtual Lab



Note. Reprinted from Transactions on Edutainment X (p. 163) by Pan Z., Cheok A.D., Müller W., Iurgel I., Petta P., Urban B., 2013, Berlin: Springer. Copyright © 2013, Springer-Verlag Berlin Heidelberg.

VLs support experimentation about unobservable phenomena such as thermodynamics, chemical reactions, or electricity (Chiu et al., 2015; De Jong et al., 2013). In addition, using VLs is a rational approach to make the interpretation of certain phenomena easier by adapting a reality (Ford & McCormack, 2000). Besides, VLs enable pre-laboratory preparation (Abdulwahed & Nagy, 2011; Dalgarno et al., 2009) and obtaining outcomes immediately (Hennessy et al., 2007). Moreover, through the experiments the prominent information can be emphasized, and confusing details can be eliminated (Trundle & Bell, 2010). However, VLs can never perform exactly the same as real hardware. In other words, as it is impossible to include all environmental parameters in the virtualisation, measurements could differ between VLs and hands-on labs for the same experiment.

2.3. Inquiry Learning Framework

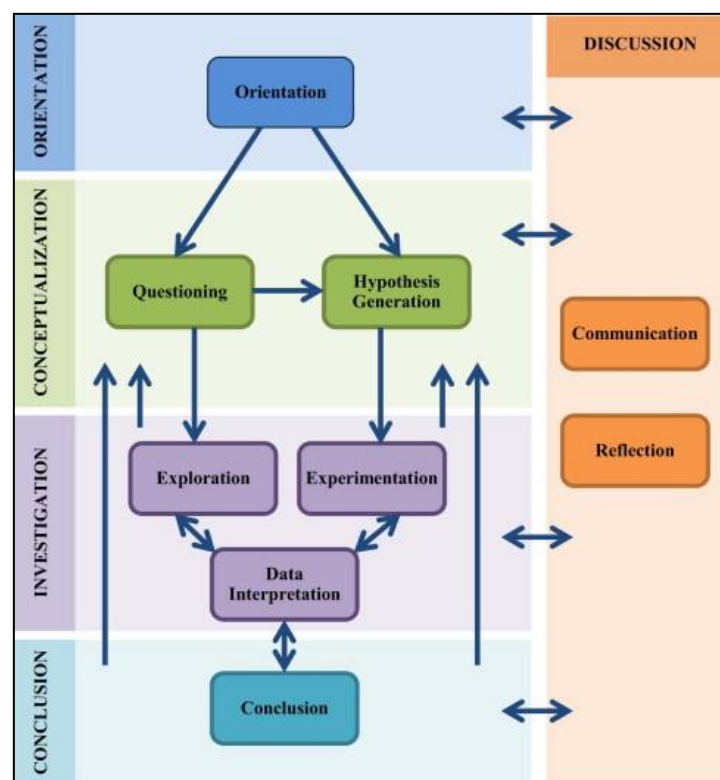
Online labs are mainly used in inquiry learning also known as discovery learning, inquiry-based learning, scientific discovery learning or project-based STEM education. Inquiry learning is a process in which students follow methods and practices similar to those of professional scientists in order to discover knowledge (Keselman, 2003). Inquiry learning is often organized into inquiry phases that together form an inquiry cycle. Pedaste et al. (2015) introduced the inquiry learning framework (see Figure 3), which consists of five phases: *Orientation*, *Conceptualization*, *Investigation*, *Conclusion*, and *Discussion*. Some of these phases are divided into sub-phases.

Orientation focuses on stimulating interest and curiosity in relation to the problem at hand (Pedaste et al., 2015). At the *Orientation* phase a learning topic is introduced either by the experimental environment itself or given by the teacher (Scanlon, Anastopoulou, Kerawalla, & Mulholland, 2011). *Conceptualization* is a process of understanding a concept or concepts

underlying the stated problem. It is divided into two sub-phases, Questioning (i.e., composing a research question) and Hypothesis Generation. *Investigation* is the phase where curiosity is turned into an action in order to respond to the stated research questions or hypotheses (Scanlon et al., 2011). This phase consists of three sub-phases: Exploration, Experimentation and Data Interpretation. Exploration sub-phase is the process of systematic and planned data generation on the basis of a research question. Students need to plan carefully in this sub-phase in order to save resources (e.g., time and/or materials). In Experimentation sub-phase student design and conduct their experiment using either VLs or RLs. In the Data Interpretation sub-phase students make meaning out of the collected data. *Conclusion* is the phase in which basic conclusions of a study are generated (De Jong, 2006). *Discussion* contains the sub-phases of Communication (i.e., students present and communicate their findings and conclusions to others and receive feedback) and Reflection (i.e., the process of reflecting on anything in a learner's mind). With regard to timing, there are two options to complete Discussion sub-phases: (1) on the whole process at the end of the inquiry learning or (2) to communicate or reflect on each single phase in the cycle.

Figure 3

Inquiry Learning Framework (General Phases, Sub-Phases, and Their Relations)



2.4. Conceptual Knowledge and Concept Learning

In STEM education, students usually draw on conceptual and procedural knowledge to accomplish tasks or solve problems. Conceptual knowledge is an understanding of definitions, rules, and principles in a domain of knowledge, while procedural knowledge is knowledge of specific strategies or actions that are used to accomplish tasks and solve problems (Van Boxtel, Van der Linden & Kanselaar, 2000). Thus, conceptual knowledge is explicit or implicit understanding of the principles and theories that establishes relationships between basic elements of a subject and lets them work together governing a domain (Rittle-Johnson & Alibali, 1999).

In other words, conceptual knowledge is general knowledge of classifications, principles, generalizations, theories, models, or structures pertinent to a particular disciplinary area. Gradually, students learn more concepts and learn how to distinguish between them (e.g., the mass is not the same as the weight of an object). They learn more than one concept to understand a complex one (e.g., ‘density’ concept is related to the ‘mass’ concept and the ‘volume’ of an object).

When students start learning a new concept or phenomenon in science education, they use naïve conceptions. In most cases, their understanding of concepts and phenomena is not consistent with scientist understanding (Chi, Slotta & De Leeuw, 1994). Therefore, students need to transform their naïve conceptions to more scientific conceptions. This transformation (i.e., the process of conceptual change) is called concept learning. *Concept learning* is the process of enrichment, organisation, reorganisation, refinement of knowledge, and the development of the ability to use scientific concepts (Van Boxtel et al., 2000). For example, before learning the ‘weight’ concept in physics, students might define their own weight as how heavy they are. However, after learning this concept students might define it as the force acting on the object due to gravity. Therefore, it is important to let students compare their preconceptions with new information, because they do not easily abandon/modify their naïve beliefs.

3. Research questions and hypotheses

Using VLs is becoming more popular in inquiry learning environments for STEM education to carry out experiments. Earlier research suggests that VLs could be as much effective as RLs (Corter et al., 2004; Tzafestas et al., 2006). However, the studies have never come to a common agreement on whether VLs and RLs are equally effective (Brinson, 2015; Lindsay & Good,

2005; Ma & Nickerson, 2006). To assess the effectiveness, the current study will focus on measuring the conceptual knowledge gain following an inquiry learning cycle in both labs. Furthermore, regardless of the effectiveness of a lab, time spent on an experiment in the Investigation phase of an inquiry learning cycle is another key indicator of whether an effective lab is also efficient. In other words, not only it is important that a lab facilitates a greater knowledge gain. It is not less important whether a lab provides a possibility to achieve a greater knowledge gain within a shorter time compared to an alternative lab. Therefore, measuring time-efficiency of VRL's is also a part of this investigation. Based on the presented theoretical framework, the following research questions and hypotheses were formulated:

3.1. Conceptual knowledge gain

Question 1. How effective is a virtual lab compared to a remote lab in inquiry learning environment?

H1: Students using virtual labs will gain as much conceptual knowledge as students using remote labs in inquiry learning environment.

Explanation: In accordance with research, each of the labs is independently as effective as a hands-on lab (e.g., De Jong et al., 2013; Faulconer & Gruss, 2018). However, the limited research base available on comparative effectiveness of VRLs has not added a clarity on whether one lab is superior over the other. The inequivalent effectiveness of VRLs takes its origins from the nature of these labs as each lab has its own strengths and weaknesses (Brinson, 2015; Lindsay & Good, 2005; Ma & Nickerson, 2006). As it follows from the framework proposed by Olympiou and Zacharia (2012), to benefit from strengths of either of the labs the choice of a lab needs to be based upon the target group (e.g., prior knowledge and skills) and the learning objectives (e.g., cognitive, affective, and psychomotor). Therefore, given the same learning objectives and the same target group characteristics used in experiments with VRLs, one of the possible outcomes is that there will be no difference in the conceptual knowledge gain between the two conditions (i.e., VL and RL). The current study is aimed at investigating the latter hypothesis.

3.2. Time-efficiency

Question 2. How efficient is a virtual lab compared to a remote lab in inquiry learning environment?

H2: Students using a virtual lab will complete their experiment in a shorter time compared to students using a remote lab for the same experiment.

Explanation: Virtual labs are expected to be more efficient than hands on labs because working with the latter objectively requires a greater time for arrangement of experiments. Besides, results of the experiments arrive with a greater delay with hands-on labs. Remote labs are similar to hands-on labs because experiments are conducted in a real lab with the only difference that a learner is not physically present in the lab. Therefore, it is expected that VLs will be more time-efficient than RLs.

3.3. The effect of learning time and lab modality on conceptual knowledge gain

Question 3. What is the correlation between conceptual knowledge gain, the amount of time spent on an experiment and the type of lab used (i.e., VL or RL) in inquiry learning environment?

H3.a: There is a positive correlation between the amount of time spent on an experiment and the conceptual knowledge regardless of a lab modality (i.e., VL or RL).

H3.b: There is no effect of the combination of the amount of time spent on an experiment and the type of lab on the conceptual knowledge gain.

Explanation: Although there is no related research in the same domain, in their meta-analysis, Cook, Levinson and Garside (2010) have found a positive relationship between increased learning time and learning outcome with the internet-based instruction. At the same time, Cook, Levinson and Garside (2010) emphasize that, due to a high heterogeneity of the findings, they cannot be generalised. The meta-analysis study suggests that efficiency is closely linked to a particular context. This conclusion is similar to the finding of Olympiou and Zacharia (2012) that success (i.e., effectiveness) of a lab modality is dependent on subjective conditions, such as learning objectives and target group. Therefore, there are two reasons to expect that for both lab modalities, the greater time is spent on experiments, the greater is the conceptual knowledge gain. First, the internet-based nature of the lesson in the current study links it to the earlier mentioned finding of Cook, Levinson, and Garside (2010). Said that, secondly, given the same learning objectives and target group characteristics for both lab modalities (i.e., VL and RL), it can be expected that for both lab modalities the relationship between learning time and knowledge gain will be positive. At the same time, there has been no scientific ground found to expect that a lab modality will affect the relationship between learning time and knowledge gain.

4. Method

4.1. Participants and Design

In total, sixty two students from the Netherlands, Jordan, and Syria participated in this study. Participants were students of the University College Utrecht (the Netherlands), the Psychology bachelor programme students of the University of Twente (the Netherlands), Jordanian and Syrian university students who were following various bachelor programmes in social science, as well as students following Dutch language learning programs in the Netherlands. The University of Twente Psychology students participated in the study to fulfil a requirement of their programme. All the other students participated in the study voluntarily.

Due to not completing one of the tests or technical difficulties while using one of the labs, twenty two students were excluded from the sample. Thus, the final sample consisted of forty students randomly assigned to the two experimental conditions: the virtual lab condition and the remote lab condition. In VL condition, there were twenty one participants (5 male, 16 female, $M_{age}= 23$ years), and in the RL condition there were nineteen participants (10 male, 9 female, $M_{age}= 26$ years). The participants' age ranged from sixteen to thirty seven years and they were competent in English. All participants had little or no knowledge about the topic of the lesson that was forces and motion in Physics (i.e., object's properties, Buoyant force, and the Archimedes principle).

The research was a quantitative, 'true' experimental design using the pretest posttest two-treatment design for measuring effectiveness (i.e., conceptual knowledge gain). Efficiency (i.e., time-efficiency) was measured by means of logging features of Go-Lab apps (www.golabz.eu/apps). Participants in both conditions conducted their experiments on the same topic that was forces and motion in Physics (i.e., object's properties, Buoyant force, and the Archimedes principle). They investigated the same hypotheses about 'density' concept and Archimedes' principle: "If the density of a cargo ship is less than the density of the water, the cargo ship will float". The experiment was divided over three moments of measurement: 1) a pretest to set a baseline for measuring prior knowledge, 2) the intervention in which participants in the VL condition used the virtual lab and students in the RL condition used the remote lab, 3) a posttest to analyse the effects of VRLs on measures of effectiveness and efficiency. The research design was as follows (Cohen, Manion & Morrison, 2013):

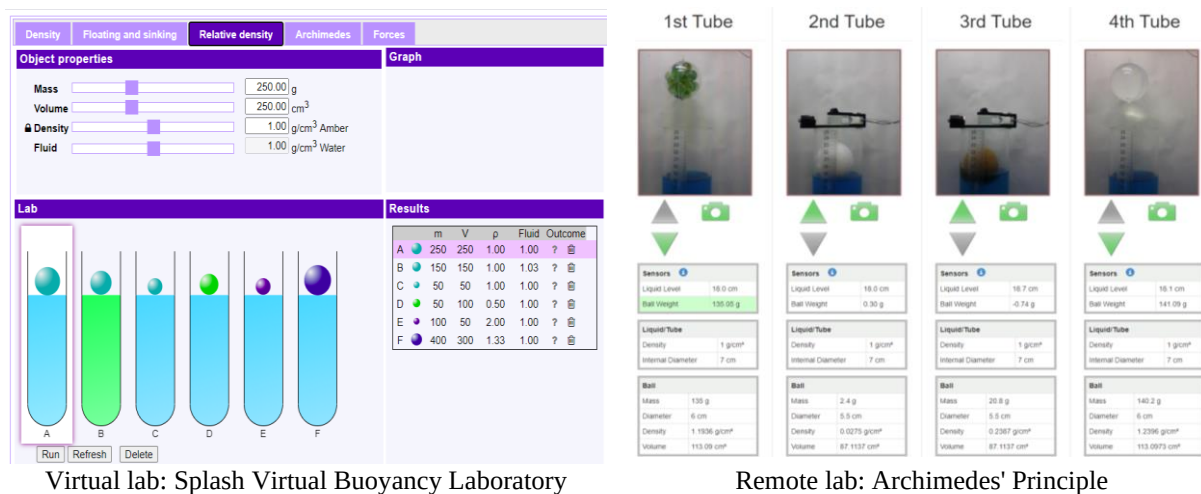
<i>VL Condition</i>	RO_1	X_1	O_2
<i>RL Condition</i>	RO_2	X_2	O_4

4.2. Instruments

Inquiry Learning Space. Two novel Inquiry Learning Spaces (ILSs) were developed in Graasp e-learning platform (www.graasp.eu). The Graasp platform allows for the creation of e-learning inquiry-based lessons using VRLs (see Figure 4) from the Go-Lab platform (www.golabz.eu). These ILSs are easy-to-build and can be created, maintained, and adjusted to fit the aim of this study. The language of the ILSs was English. The ILSs entailed the informed consent, learning objectives, introduction, and the five phases of the inquiry cycle (i.e., Orientation, Conceptualization, Investigation, Conclusion and Discussion). Pretest was included in the Introduction phase and the posttest was included in the Discussion phase. Both ILSs were identical, except for the Investigation phase: ILS A ([ILS-A](#)) contained the virtual lab (i.e., [Splash: Virtual Buoyancy Laboratory](#)) whereas ILS B ([ILS-B](#)) contained the remote lab (i.e., [Archimedes' Principle](#)). To ensure comparable investigation outcomes, both ILSs included the same ready-to-use hypothesis in the Conceptualization phase.

Figure 4

Virtual and Remote Labs



Domain Knowledge Test. Two knowledge tests (i.e., pretest and posttest) were integrated in the ILSs using the Quiz app (golabz.eu/app/quiz-tool) from the Go-Lab platform. The Quiz app allows creating quizzes containing multiple choice, multiple select, and two-way (yes/no) questions. The pretest and posttest had an identical content (see appendix C). Each test consisted of fifteen questions, 3 multiple choice questions with 4 alternatives each and 12 yes/no questions, measuring participants' conceptual knowledge gain in the domain. With regard to the multiple-choice questions more than one alternative answer could be correct. Thus, the questions tested the participants' knowledge (De Jong & Ferguson-Hessler, 1996) of the

objects' properties (i.e., mass, weight, volume, and density), Buoyant force and the Archimedes' principle. The conceptual knowledge questions asked participants to recognize the main concepts related to Buoyant force (e.g., 'The density of an object is its weight per unit volume: Yes/No'). Each correctly answered yes/no question scored one point and each correctly chosen alternative scored one point. The final score of a participant for the test was calculated by summing up all points and the maximum score was nineteen points. The final version of the domain knowledge test was tested in a pilot study, which indicated that the questions were suitable for participants.

Go-Lab Apps. Several Go-Lab platform apps, such as Quiz Overview (premium.golabz.eu/services/premium-apps) and Time spent Summary (golabz.eu/app/time-spent-summary), were integrated in the ILSs to collect data during the experiments (please see appendices D and E).

4.3. Procedure

Via the distributed link, participants were invited to follow an online Physics lesson in forces and motion. They were asked to enter a nickname to log in and had to give their informed consent (see appendix A) to start the lesson. Participants were recommended to read the learning objectives (see appendix B) and were invited to complete the pretest (see appendix C). Next, they were asked to follow the inquiry learning cycle and to conduct their experiments using the labs that were integrated in the Investigation phase. At the end of the Discussion phase participants had to take the posttest and provide their age and gender. These activities took place online and were estimated to take no longer than fifty five minutes in total. The following lengths of time were estimated to be spent on each phase: Introduction including the pretest – 10 minutes, Orientation – 10 minutes, Conceptualization – 5 minutes, Investigation – fifteen minutes, Conclusion – 5 minutes, and Discussion including the posttest – 10 minutes.

4.4. Data Analysis

The data analysis involved quantitative methods. With respect to the hypothesis 1, a t-test was performed to find out statistical significance of differences between the means of the pretest and posttest scores. VRLs were the independent variables, whereas the differences between the posttest and pretest scores (i.e., the conceptual knowledge gain) were the dependent variable. Similarly, with respect to the hypothesis 2, a t-test was used to compare time spent by both experimental groups (i.e., condition VL and RL) while they were using VRLs. VRLs are the independent variable, and time spent by experimental groups were the dependent variable.

5. Results

5.1. Conceptual knowledge gain

Table 1 shows the descriptive statistics for the two research conditions. In one condition, participants ($n=21$) used the virtual lab named “Splash Virtual Buoyancy Laboratory” integrated into the ILS A (i.e., VL condition). In the other condition, the participants ($n=19$) used the remote lab named “Archimedes' Principle” integrated in the ILS B (i.e., RL condition). An independent samples t test was used to compare the gained points after using the labs. Both Shapiro-Wilk tests were statistically non-significant at $\alpha = .05$, confirming that the normality assumption was not violated in the VL and RL conditions. Levene's test was also non-significant, thus equal variance can be assumed. The t test showed no significant difference between the conditions, $t(38) = 0.46$, $p = 0.65$.

Table 1

Scores by Research Conditions

Research condition	Pretest M (SD)	Posttest M (SD)	Gained Points M (SD)
VL Condition ($n=21$)	8.24 (2.30)	11.19 (2.56)	2.95 (2.75)
RL Condition ($n=19$)	9.32 (2.85)	11.89 (3.11)	2.58 (2.34)
Total ($n=40$)	8.75 (2.60)	11.53 (2.82)	2.78 (2.54)

A two-tailed, paired samples t test with an alpha level of 0.05 was used to compare the VL condition pretest ($M = 8.24$, $SD = 2.30$) and posttest ($M = 11.19$, $SD = 2.56$) scores of 21 participants. On average, participants' posttest scores were only 2.95 points higher than their pretest scores, 95% CI [1.70, 4.20]. However, this difference was statistically significant, $t(20) = 4.93$, $p < 0.001$. Cohen's d for this test was 1.21, which can be described as large. Visual inspection of the relevant histograms indicated that neither the normality nor normality of difference scores assumptions were violated.

Similarly, a two-tailed, paired samples t test with an alpha level of 0.05 was used to compare the RL condition pretest ($M = 9.32$, $SD = 2.85$) and posttest ($M = 11.89$, $SD = 3.11$) scores of 19 participants. On average, participants' posttest scores were only 2.58 points higher than their pretest scores, 95% CI [1.45, 3.71]. However, this difference was statistically significant, $t(18) = 4.80$, $p < 0.001$, and large, $d = 0.87$. It was concluded that the assumptions normality and normality of difference scores were not violated after outputting and visually inspecting of the relevant histograms.

5.2. Time-efficiency

An independent samples *t* test was used to compare an average time in seconds spent by participants on the Investigation phase in the VL condition ($M = 580$, $SD = 205$) to that of participants in the RL condition ($M = 653$, $SD = 211$). Neither of the Shapiro-Wilk statistics was significant, which indicated that the assumption of normality was not violated. Levene's test was also non-significant, thus equal variances could be assumed. The *t* test was statistically non-significant, $t(38) = -1.11$, $p = 0.28$.

Furthermore, an independent samples *t* test was used to compare an average time spent in seconds by participants on all the five phases of inquiry learning cycle (i.e., Orientation, Conceptualization, Investigation, Conclusion, and Discussion) in the VL condition ($M = 1956$, $SD = 420$) to that of participants in the RL condition ($M = 2169$, $SD = 449$). Neither of the Shapiro-Wilk statistics was significant, which indicated that the assumption of normality was not violated. Levene's test was also non-significant, thus equal variances could be assumed. The *t* test was statistically non-significant, $t(38) = -1.55$, $p = 0.129$.

5.3. The effect of learning time

To assess the size and direction of the linear relationship between the time spent on experimenting with VRLs and conceptual knowledge gain, a bivariate Pearson's correlation coefficient (*r*) was calculated, $r(38) = -0.08$, $P = 0.61$. Prior to calculating *r*, the assumptions of normality, linearity and homoscedasticity were assessed and were supported. Specifically, a visual inspection of the normal Q-Q and de-trended Q-Q plots for each variable confirmed that both were normally distributed. Similarly, visually inspecting a scatterplot of time spent against conceptual knowledge gain confirmed that the relationship between these variables was linear and heteroscedastic.

5.4. The effect of time and a lab modality

Partial correlation was used to assess the linear relationship between time spent and conceptual knowledge gain, after controlling for a lab modality. The partial correlation was statistically non-significant, $r(37) = -0.07$, $P = 0.68$. After partialling out a lab modality, just 0.49% of the variability in conceptual knowledge gain could be accounted for by the variability in time spent.

6. Discussion and Conclusion

Both, virtual and remote labs are broadly used to engage students in the inquiry learning activities. Each of the labs has its own advantages and can be used for specific purposes. In

some situations, there is no explicit advantage of one lab over the other since both types might be effective. This study sets out to determine the effect of a lab modality on conceptual knowledge gain, the time-efficiency of VRLs, and the effect of learning time and a lab modality on conceptual knowledge gain. Importantly, ILSs for the two investigated conditions were identical in the current study. The only difference in the ILSs between the two conditions was in using two different labs (i.e., VL and RL) in the Investigation phase.

There has been no consensus regarding the effectiveness of virtual and remote labs (Brinson, 2015; Ma & Nickerson, 2006). So, it has been assumed that VLs and RLs have the same effect on conceptual knowledge. In the current study, a positive effect of the virtual and remote labs was found with respect to conceptual knowledge acquisition. However, participants in the VL condition did not outperform participants in the RL condition. The findings are in line with the Corter et al.'s study (2004) and the Tzafestas et al.'s study (2006). Thus, both labs could be considered to be effective and be used to conduct experiments in inquiry learning.

One possible explanation for such an outcome could be that previously found inequivalent effectiveness of VRLs is caused by unique affordances of VLs and RLs. Indeed, in the current, study the unique affordances of VRL's that make each lab modality distinct were not employed. For example, with VL, there was no need to simplify the concepts under consideration in order to make them more visible to participants and adaptable to multiple cognitive levels. In the same way, in the current investigation, with RL the true measurement errors were inexistent. The second possible explanation could be that the content of Orientation phase, being identical for the two conditions, was rather too informative. In other words, the outcome of this phase was not limited to the problem statement only, which should have been the main goal of the Orientation phase (Pedaste et al., 2015), but contributed to learning of the participants in both conditions.

The results of the current study reveal that, between VL and RL there is no difference in time spent either in the Investigation phase or in the complete inquiry learning cycle. This result does not support the earlier findings of De Jong et al. (2013) and Heradio et al. (2016). Heradio et al. suggest that, in virtual labs, students can perform a wide range of experiments faster and more easily receive an immediate feedback on errors, which enables them to repeat the same experiment immediately. One reason for such an outcome could be that RL experiments used in the Investigation phase of the current study were pre-set. Consequently, there was no additional time required to make any adjustments to the existing setup.

Moreover, in overall, the data showed that neither increased learning time nor a lab modality had any effect on conceptual knowledge gain. Hence, the amount of time spent by a student on an experiment does not affect his or her conceptual knowledge gain, regardless of whether the student is using a virtual or a remote lab. One explanation for the result could be that, if an additional time is given for learning, there needs to be an additional guidance of learners. Indeed, as Lazonder and Harmsen (2016) highlighted, the more adequate is a guidance of learners, the more effective is inquiry learning. Another explanation could be that in both lab modalities guidance of learners was precise and detailed enough for them not to need an extra time for an additional learning gain. Besides, the investigation time (i.e., the time spent in a lab completing the Investigation phase) was relatively short in the current experiment and not sufficient to demonstrate the effect.

This research has thrown up many questions in need of further investigation. As aforementioned, in the current study unique affordances of VRLs were not employed, which could have impacted the results. Further studies with labs, whereby their unique affordances could be enabled, would shed the light on whether the inequivalent effectiveness of VRLs found in the previous studies could have been caused by the unique affordances of VLs and RLs. Therefore, the findings call for an in-depth investigation of the labs' effectiveness from the design perspective. Practices, such as information design (i.e., cues), interaction design (i.e., feedback) and design of instructional guidance (e.g., scaffolding and prompts) play a crucial role in determining the effectiveness of the labs (Mayer, 2014; Zacharia, 2015). Both labs used in this study lacked for these practices. Besides, the instruction on how to use the labs was specifically developed for the purpose of this study (e.g., "to drop an object into the liquid, click on the "▼" down arrow icon") and might have been not sufficient (see appendix F).

Other factors, such as accessibility and readability, should be considered to determine effectiveness and efficiency of remote labs. To illustrate, some participants were confused because the vision was not clear, they were not able to decide whether the ball sank or hung into the water. Therefore, further research is needed to investigate which design factors are crucial to determine effectiveness and efficiency of virtual and remote labs. The limitation of this study was inexistence of identical virtual and remote labs in the Go-Lab platform. Another limitation was a restricted number of remote labs in the Go-Lab platform, many of which did not function. These limitations restricted the choice of the subject to physics and that might have had an influence on effectiveness.

Overall, the current research is novel to academia from two perspectives. First, it has stepped into investigation of VRLs time-efficiency. No significant difference in time-efficiency of VRL's implies that with no additional design improvements, none of the labs can be superior with regard to time-efficiency. In this connection, for instance, studying time-efficiency of the labs with integrated feedback, as discussed in the works of De Jong et al. (2013) and Heradio et al. (2016), might shed more light on how to improve the labs' time-efficiency. With regard to the practical implications, the results of this study indicate that schools, universities, and other educational institutions can benefit from both, RLs or VLs, since there is no difference between their effectiveness and efficiency. However, other issues such as cost, sustainability and deliverability should be considered before deciding on which modality of labs to choose. These practical issues might explain why the number of VRLs is greater than the number of RLs in the Go-Lab platform, despite no difference between the effectiveness and efficiency of the labs. In addition, Go-Lab developers and other instructional designers should be aware of the principles of multimedia learning, information design, interaction design, and design of instructional guidance that might play a major role in determining the effectiveness and efficiency of VRLs.

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Appendix A – Informed Consent

Informed Consent (Online Lesson)

This online lesson is being distributed in support of a research project being conducted by Khaldoon Al Krad in partial fulfilment of his master's degree in Educational Science and Technology, the University of Twente. This lesson is estimated to take approximately 50 minutes to complete.

Title of the Research Project: How Effective and Efficient Is a Virtual Lab Compared to a Remote Lab in Inquiry Learning Environment?

Principal Investigator: Khaldoon Al Krad

Voluntary participation: Your participation in this research project is completely voluntary. You have the right to withdraw at any time. Participants can withdraw at any time prior to the completion of the online lesson by simply abandoning the lesson. No personal data such as your name will be collected except your age and your gender. Please note that there are no risks associated with your participation. All the results will be used for educational purposes.

- I am 16 years or older

- ☐ Yes
- ☐ No

- I have read the information and I agree

- ☐ Yes
- ☐ No

Appendix B – Learning Objectives

Buoyant Force

Welcome to this introduction on Buoyant Force! At the end of this lesson, you will be able to:

- What?**
- 1- Recognize object's properties (i.e., mass, weight, volume, and density) and their units.
 - 2- Investigate the relationship between density and floating (i.e., Why some objects float while others sink?)
 - 3- Explain what the Buoyant force and the Archimedes principle are.

Why? In some situations, perceiving Buoyant force can save lives. Think about cruise ships and other large vessels: why do they float as they move forward in the water.

How? In order to discover Buoyant Force, you need to act as scientists and complete the inquiry learning cycle. You have to complete the 5 phases of the inquiry learning cycle:

1. Orientation
2. Conceptualization
3. Investigation
4. Conclusion
5. Discussion

You will watch YouTube videos and practice in a Splash lab to discover Buoyancy and investigate your hypotheses (i.e., theories) about forces in fluids.

Appendix C – Pretest and Posttest

1- Is an object's mass the same as an object's weight on the Moon?

- ☐ Yes
- ☐ No
- ☐ I do not know.

2- Which of the following is true about an object's mass (m)?

- ☐ Mass is a measure of the amount of matter in an object.
- ☐ The unit of mass is measured in grams (g) or kilograms (kg).
- ☐ Your mass on the Earth and the Moon are not identical.
- ☐ An object's mass is constant in all circumstances.

3- The density of an object is its weight per unit volume.

- ☐ Yes
- ☐ No
- ☐ I do not know.

4- The formula for density is $d = m/v$, where d is density, m is mass, and v is volume, and the unit of density is measured in kilogram per cubic metre (kg/m^3).

- ☐ Yes
- ☐ No
- ☐ I do not know.

5- Which of the following is true about object's weight (w)?

- ☐ Object's weight is the force exerted on a body by gravity.
- ☐ The unit of weight is measured in newton (N).
- ☐ Weight is a force.
- ☐ Your weight on the Moon is so much more than your weight on the Earth?

6- What causes objects to sink or float?

- ☐ Object's weight.
- ☐ Object's volume.
- ☐ Object's mass.
- ☐ Object's density.

7- If the boat weighs less than the maximum volume of water it could push aside (displace), it sinks.

- ☐ Yes
- ☐ No
- ☐ I do not know.

8- When an object enters water, two forces act upon it: electric force and gravitational force.

- ☐ Yes
- ☐ No

- ☐ I do not know.

9- An object floats when the weight force on the object is balanced by the upward push of the water on the object.

- ☐ Yes
- ☐ No
- ☐ I do not know.

10- The buoyant force is present whether if an object floats or sinks.

- ☐ Yes
- ☐ No
- ☐ I do not know.

11- The buoyant force comes from the pressure exerted on the object by the fluid. Because the pressure increases as the depth increases, the pressure on the bottom of an object is always larger than the force on the top - hence the net upward force.

- ☐ Yes
- ☐ No
- ☐ I do not know.

12- Archimedes principle is: The buoyant force exerted on a body immersed in a fluid is equal to the mass of the fluid the body displaces.

- ☐ Yes
- ☐ No
- ☐ I do not know.

13- You can calculate the buoyant force on an object by adding up the forces exerted on all of an object's sides.

- ☐ Yes
- ☐ No
- ☐ I do not know.

14- The buoyancy force on a completely submerged object of volume is $F_B = v\rho g$, where v is the volume of the object, ρ is the density of the fluid, and g is gravitational acceleration.

- ☐ Yes
- ☐ No
- ☐ I do not know.

15- Archimedes suggested that: any object, totally or partially immersed in a fluid or liquid, is buoyed up by a force equal to the weight of the fluid displaced by the object.

- ☐ Yes
- ☐ No
- ☐ I do not know.

Appendix D – Quiz Overview App

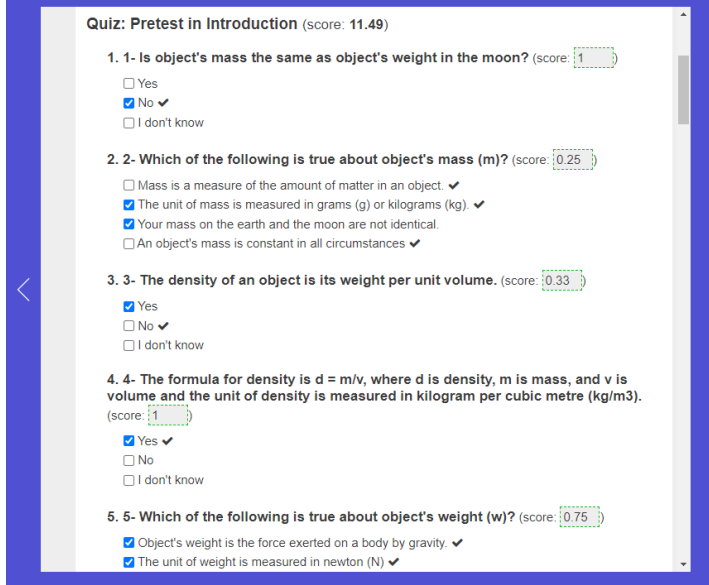
All students overview for each question



One student's answers overview for all questions

Quiz Overview 

Buoyant Force A > Teacher Dashboard
Write a description here



Quiz: Pretest in Introduction (score: 11.49)

1. 1- Is object's mass the same as object's weight in the moon? (score: 1)

☐ Yes
☒ No ✓
☐ I don't know

2. 2- Which of the following is true about object's mass (m)? (score: 0.25)

☐ Mass is a measure of the amount of matter in an object. ✓
☒ The unit of mass is measured in grams (g) or kilograms (kg). ✓
☒ Your mass on the earth and the moon are not identical.
☐ An object's mass is constant in all circumstances ✓

3. 3- The density of an object is its weight per unit volume. (score: 0.33)

☒ Yes
☐ No ✓
☐ I don't know

4. 4- The formula for density is $d = m/v$, where d is density, m is mass, and v is volume and the unit of density is measured in kilogram per cubic metre (kg/m³). (score: 1)

☒ Yes ✓
☐ No
☐ I don't know

5. 5- Which of the following is true about object's weight (w)? (score: 0.75)

☒ Object's weight is the force exerted on a body by gravity. ✓
☒ The unit of weight is measured in newton (N) ✓

<https://nlwente.graasp.eu/production/quizOverview/build/quizOverview.html>
0 likes, 71 views



Appendix E – Time Spent Summary App

A visual Explanation of the time spent on each phase



Appendix F – Using Instructions

Instructions for Using Splash Lab

- In this lab you can create objects from 'Object properties' such as mass, volume, and density, and drop these objects in a tube filled with a fluid.
- You can choose the density of the fluid, allowing you to discover the interaction between object properties and fluid density.
- You can measure the amount of fluid displaced by the object and discover Archimedes' Principle.

How to use the lab?

1. Select '**Relative density**' tab (i.e., the **third tab** below).
2. Select the **object** and then use the **sliders** to change object properties and the fluid.
3. Press '**Run**' to drop objects in the tubes.
4. All the **values** will appear in a table beside the tubes.
5. Write down your observations in the tool below the lab.
6. You can repeat the experimentation as much as you need by clicking on '**Refresh**'.

Instructions for Using Archimedes' Principle Lab

- In this lab you have 13 objects and tubes filled with liquid, please scroll down to see all the tubes.
- To choose which tube to show or hide, simply click on their button to toggle their state (e.g., click on "1st Tube" button to show/hide it).

How to use the lab?

1. Press the button "**Access the lab**".
2. To **drop** an object into the liquid, click on the "▼" down arrow icon.
3. To **rise** an object from the liquid, click on the "▲" up arrow icon.
4. All the **values** will appear under each object.
5. Write down your observations in the tool below the lab.