Multi-User Virtual Laboratory: Soft Aspects of Hard Science

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Abstract

As collaboration has become a 21st century trend and online learning has blended into the mainstream of education, there is a need to re-consider learning instruction by taking into account the multitude of e-learning environments. Computer-supported collaborative learning is an educational approach that not only connects remote peers but also uses technology to shape interactions, a most important factor in enhancing learning in science courses. In this study we investigate the benefits of collaborative learning in a virtual reality science lab environment. We converted Onlabs, a single-user, 3D, desktop-based virtual reality educational software that simulates the environment of a biology lab, to a collaborative application. In the Onlabs original version, the users could be trained and familiarized individually on the instruments and equipment of their biology experiments, through audio and written instructions that appear on the PC screen. However, in the presented enhanced Onlabs version, multiple users can now collaborate in the virtual lab and interact as a group of peers to implement a specific experiment, while the lab tutor is also present, but only as an observer. The main axis of our research is the operation of a photonic microscope, one of the basic instruments in a biology lab. A sample of Lyceum learners from a secondary education school in Greece, was partitioned into three groups to be trained on the microscopy experiment by three different educational scenarios. The first group was conventionally trained in the physical lab, the second group was trained in the computer lab using the single-user mode of Onlabs and the third group was trained also in the computer lab using the multi-user mode of the software. Finally, the acquired laboratory skills were assessed in the physical biology lab, where all three groups were asked to use a photonic microscope and focus on a given specimen. Our study provided an initial body of evidence that collaboration and social interaction in a multi-user virtual reality learning environment contributes to higher performance regarding the achievements of the learning goals. Still, the concurrent presence of several people in the same virtual space, which does not come with socially relevant complementary cues, such as body language, seems to elevate the stress level of some participants, therefore

rendering the whole set-up as worth investigating from a variety of angles. With the certain assumption that physical labs are essential in science courses, there is a need for institutions to become attuned to this new need of the digital age to design educational scenarios that are based on technological innovations.

Keywords: distance education, multi-users virtual laboratories, desktop-based virtual reality, collaborative learning.

1. Introduction

The teaching methodology of Science is changing rapidly due to the development of technological applications that can be incorporated into the learning procedure (Elme et al., 2022). However, it is not always feasible to offer graduate students specialized spacious labs, updated equipment and enough lab instructors, especially nowadays that many educational institutions face financial problems (Hess, 2021; Sheng & Zhao, 2021). Universities may struggle to meet the traditional prerequisites that guarantee quality in science laboratory education and as a result, they try to change the way science subjects are being taught. Additionally, the classical teaching scenarios in science laboratory courses are no longer appealing to the new generation who is born and lives in a digital age where technology dominates her life (Paxinou et al., 2018a). This generation favors universities that exploit the promising potentials of the digital technology in order to modernize the teaching methodologies (Paxinou et al., 2022). The "digital natives", as so aptly called by Mark Prensky (2001), seek for cool ways to access knowledge asynchronously, and from any location.

In order to boost students' engagement with lab science, today's educators, even those who until recently were not in favor of the synchronous or asynchronous online learning, are exploring the educational potentials of the digital technology. Virtual Reality (VR) is a cutting-edge technology that can be used in online learning to display a wide range of lessons (Ott & Freina, 2015; Garzon, 2017; Xu, 2018; Fernandes & Damasceno, 2021; Paxinou et al., 2022). Depending on the equipment used, VR vary in the level of immersion the user experiences (Bowman & McMahan, 2007). Desktop-based VR may offer a low-immersive experience, whereas a head-mounted display offers a high level of immersion (Cummings & Bailenson, 2016). Desktop-based VR is easy to use and most importantly, it does not acquire specific and expensive equipment: a PC, a keyboard or a mouse are all the user needs. In a, as realistic as possible, desktop-based VR environment, the user can experience any task, even those who are difficult or dangerous to perform in the real world.

Many studies present that desktop-based VR may promote affective autonomous learning processes and engage students in the learning process, in many different scientific fields (Yang et al., 2018; Parong & Mayer, 2021; Paxinou, 2021a, 2021b, 2021c). As a result, a VR application can be included in a distance learning educational scenario in science lab courses, in the sense that it promotes the independent and self-directed construction of knowledge. On the other hand, the collaboration, the interaction and the communication between the learners in the physical lab environment is essential, as they contribute to content learning and development of laboratory skills (Thrope, 2002). In this study we use a multi-user VR application, as an attempt to combine the autonomous and the collaborative learning, two contrasting concepts that are both essential in distance learning environments (Paulsen, 1993). In particular, we investigate whether an instruction-assisted, multi-user, collaborative VR educational software can help students acquire the basic hands-on science skills that are essential for performing their experiments in the physical biology lab.

In our research we compare the performance of students who were either trained on the microscopy experiment with the traditional face-to-face methodology or with the single-user version of a VR educational software or with the multi-user collaborative version of a VR educational software. We use the VR application named Onlabs, an interactive virtual lab that simulates basic lab experiments that usually occur in a biology wet lab. Onlabs is a digital educational material that is offered to distance learning students enrolled in the postgraduate program "Studies in Natural Sciences" at the Hellenic Open University (HOU). Students that attend the laboratory biology modules of this program, are prepared for their lab experiments by interacting with the virtual lab equipment of Onlabs, at home. In other words, the students except from studying the given printed material or watching the educational videos, they are practicing on their experiments by distance, via Onlabs before appearing in the university premises to conduct live the same experiments.

In this empirical study, in order to give answers to the research questions, three groups of students enrolled in a biology lab course, were educated in the microscopy experiment following a different training method: the traditional face-to face lab tutorial in the physical lab or the private self-training trough interaction with a virtual microscope or finally the collaborative training trough interaction with a virtual microscope. The study provided indications that collaboration in a multi-user virtual reality learning environment contributes to higher performance, regarding the achievements of the learning goals of a science laboratory course.

2. Background and Related Work

As mentioned in the previous chapter, a virtual biology laboratory class, supplied with high level of immersion and interaction, could serve as a powerful tool for initiating students to the daily routine in the on-site laboratory, enhancing and further enriching their practical experience (virtually though) and offering them the opportunity to experiment safely and unrestrictedly on things they could not do in reality and learn by trial-and-error. Such realistic and instructive virtual labs are Labster, developed by the Danish multi-national company of the same name[1], and Learnexx 3D, developed by Solvexx Solutions Ltd, based in the UK[2].

The Second Life platform has also been used for the virtual recreation of medical procedures, where the users are being trained in providing healthcare and medical services. Imperial College's Virtual Hospital and Polyclinic and University of California's Virtual Pharmacy consist of some of Second Life's most characteristic medical worlds (Lee & Berge, 2011).

In the past, several interactive computer-based applications for science and biology learning have been developed and tested and claimed encouraging learning results. For example, 212 junior high school students (13-14 years old) in Greece were provided with an interactive 3D animation, accompanied by narration and text, dealing with "methods of separation of mixtures" which in general, did increase the students' interest in science (Korakakis et al., 2009). Also, 44 magnet science and medical technology high school students (17-18 years old) in Texas, USA, improved their molecular biology skills by using a computer-based simulation designed for training in the production of a transgenic mouse model, independently of their previous knowledge of it (Shegog et al., 2012). Moreover, a virtual world under the name of Multiplayer Educational Gaming Application (MEGA) was designed for and used by 131 US college prep students in which they had to solve a CSI-like murder case using their skills of scientific inquiry and eventually, 94% of the participant students practiced successfully their basic scientific skills to solve the case (Annetta et al., 2010).

3. Onlabs Virtual Biology Laboratory

Hellenic Open University has been developing its virtual biology lab, Onlabs, since 2012; from 2012 to 2015 under Hive, a 3D game engine developed by Eyelead[3], and from 2016 until today under Unity. Onlabs's main

[1] https://www.labster.com/
[2] http://learnexx.com/
[3] A computer game company based in Athens, Greece.

traits are its state-of-the-art 3D graphics and realistic interaction simulation. In Onlabs, the user navigates with the arrow keys and interacts with the simulated instruments with the mouse and performs virtual experiments.

3.1 **Single-user version of Onlabs**

Latest stable version of single-user Onlabs is version 2.1.2 and can be downloaded from our website[4] for free. It includes the simulation of two separate experiments, those of the microscoping of a test specimen and the preparation of 500ml of 10X TBE water solution. The first procedure involves the setting of the photonic microscope and the creation of a test specimen as well as its microscoping with the microscope's objective lenses, while the second one involves the weighting of boric acid and trizma base powders and their dissolution in water with the magnetic stirrer along with the addition of EDTA pH 8.0 and water to the produced solution. It also includes three different modes of playing, those of *instruction*, where the human user is guided by voice and text and is allowed to perform only the suggested move each time; *evaluation*, where the human user is free to make any move they want with respect to the selected experiment while being evaluated on their performance; and *experimentation*, where the human user is free to make any permitted action they want with all equipment available from both simulated procedures and without receiving any evaluation. A screenshot of Onlabs 2.1.2 is shown in Figure 1.

Figure 1: A screenshot of Onlabs latest version 2.1.2.

2.1. Multi-user version of Onlabs

The collaborative multi-user version of Onlabs is based on single-user Onlabs version 2.1.2 and has incorporated the single-user features in the latter's Instruction Mode and for the moment, concerns only the microscoping procedure. It runs as a desktop application on Windows and Mac systems. For the conversion of the single-user version to the multi-user one, we used a plug-in package (PUN2 Free) of the Photon Engine[5]. Multi-user version of Onlabs is described below.

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[4] http://onlabs.eap.gr/

[5] https://www.photonengine.com/

At first, each student chooses a nickname and finds an existing room, or creates a new one (Figure 2).

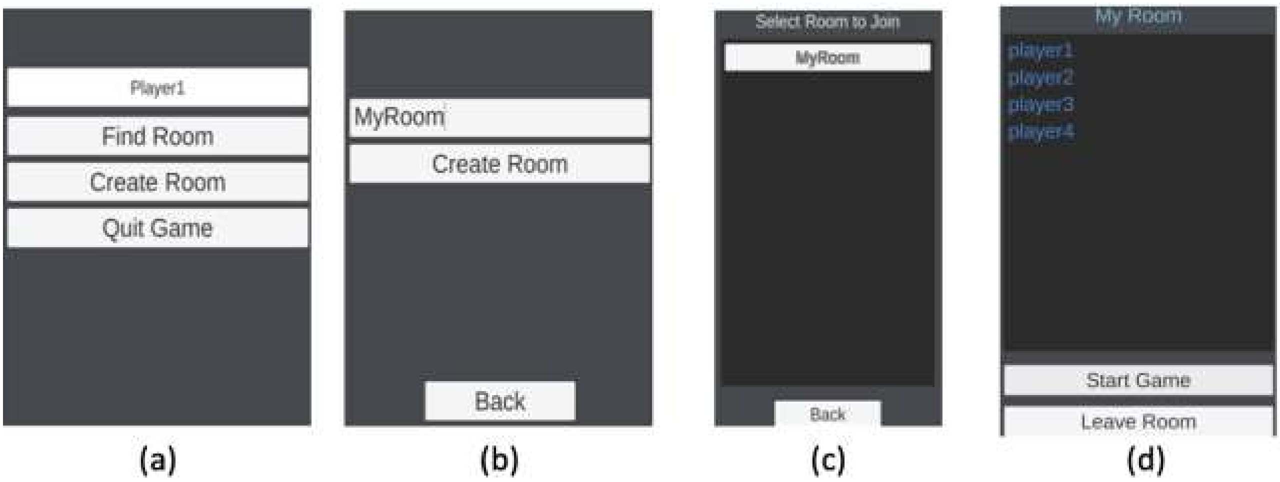

Figure 2: Menus for the configuration of multi-using.

As soon as all students have joined to the same room, master client (room owner) starts the game. The students are simultaneously transferred to the virtual lab, in front of a bench with 4 microscopes, and a message with the first instruction appears on all users' (players') screens. Each microscope has the nickname of a student on a tag over it (Figure 3) and each student needs to navigate to the respective microscope.

Figure 3: Scene of the virtual lab when all users (players) have joined.

The students interact with microscopes parts through the mouse and each one has to correctly follow the particular instruction. A step is completed when the respective instruction is followed by all of the students. After the completion of a particular step by all students, the latter are prompted with the next step. If, however, someone cannot implement the instruction, there is the option of asking for help.

Help function is implemented by selecting from a drop-down list of joined students the student to be called for help, and pressing the help button (Figure 4). When help button is pressed, a message for help is being shown to all students (Figure 5) and the student chosen to help is allowed to perform the required action on the microscope of the student who made the request.

Figure 4: Selecting player from a drop-down list.

Figure 5: Help message that appears on all players' screen.

The training process is completed when all learners (players) have correctly implemented all the required 25 steps.

4. The Empirical Study

In science education, there is a debate between the traditional and the VR lab, as "*the former offers a unique hands-on experience and a positive research-training environment with a social experience of working with others, whereas the latter offers safe and repeated practice in combination with a unique engaging feeling*" (Paxinou, 2020:3). Additionally, many studies indicate that training in a collaborative VR environment leads to better learning outcomes. According to Papanastasiou et al., (2019) such collaborative experiences enhance the ability to memorize and to build the knowledge in new concepts. On the other hand, researchers like Choi & Baek (2011) argue that there is no substantial difference in achieving the learning goals when comparing a VR collaborative learning environment and a face-to-face survivorship training. In order to take part on this debate, we conducted an empirical study to give answers to the following research questions:

(a) The instruction-assisted multi-user collaborative version of Onlabs software may help students acquire the basic hands-on science skills that are essential for conducting their experiments in the physical lab?

(b) Finally, which group of students has better performance in conducting an experiment in the physical lab? The group who was trained by following the traditional teaching method or the two groups who were trained through interaction with the virtual instruments of the Onlabs software?

4.1 The Participants

The sample consisted of 12 upper secondary education (Lyceum) students from the city of Lefkada in Greece. The Lyceum students were enrolled in a biology course, a course where, among other tasks, they are practicing in biology experiments in the school lab. This sample represents a novice audience that brings a zero to minimum prior knowledge on the operation of a photonic microscope. The students were divided into 3 groups to be educated on the microscopy experiment with a different teaching methodology.

4.2 The Educational Scenario

The educational scenario was completed in 2 phases. The purpose of the 1st phase was to train the students on the specific experiment, whereas the purpose of the 2nd phase was to perform the experiment in the real lab and evaluate this performance.

The 1st Phase

During the 1st phase, the 12 students were divided into 3 groups of 4 students each, and were educated in the microscopy experiment by different methodologies (Table 1). The Group A entered the biology school lab and watched the biology teacher performing the microscopy experiment. Then each students tried to operate the physical microscope on his/her own. The Group B entered the computer school lab and each student used her/his own PC to interact with the single-user version of the Instruction Mode of Onlabs. The Group C entered also the computer school lab but the learners of this Group interacted with the new multi-user version of Onlabs. The training of all three groups lasted almost 20 minutes.

Table 1. The 2 phases of the empirical study scenario.

	1st Phase • Training in the Microscopy Experiment		
Group	A	B	C
Location	Biology school lab	Computer school lab	Computer school lab
Duration	20min	20min	25min
Learning Methodology	Face-to-face lab tutorial	Interaction with the single-user version of Onlabs	Interaction with the multi-user collaborative version of Onlabs
	2nd Phase • Performing the Microscopy Experiment in the Real Lab with a Real Microscope • Evaluation of the Laboratory Skills		

The 2nd Phase

During the 2nd phase, all 12 students entered the school biology lab to conduct the microscopy experiment. The biology teacher was watching them to evaluated their performance. This evaluation was based on a questionnaire specially designed by E. Paxinou (2020:159). According to this questionnaire, the complete microscopy experiment was divided into 24 steps. The students had to follow the instructions of these 24 steps in the given order. After completing (or not) each step the teacher had to tick on one of the three following options: (a) the student performed the step easily, (b) the student performed the step with difficulty or (c) the student was unable to perform the step and asked for help. A small part of the questionnaire (step 6 of the experiment) is presented in Table 2. It is obvious that those students who performed without difficulty most of the 24 steps, are the students with the highest performance, and the training methodology they followed is the favourite one.

Table 2: A part of the evaluation questionnaire.

Step N°	6
Instruction	Rotate the revolving nosepiece so as to set the objective lens with the lowest magnification into position
Students' Performance *(Tick on one of the three options)*	(a) The student performed the step easily (b) The student performed the step with difficulty (c) The student was unable to perform the step and asked for help

4.3 **The Results**

1st Phase

In computer supported collaboration learning, educational processes are usually supported by text-based prompting tools that are used to help and make the interaction productive (Wang et al., 2017; Schnaubert & Bodemer, 2019). In the single-user version of Onlabs there is a globe button that offers the learners simultaneous written and audio hits (with exactly the same content) for each step of the experiment. In the multi-user version of Onlabs the learners have the option to call a classmate, who is also present in the virtual lab, to complete the step for them. So, in the 1st phase where the training occurred, two students from Group C used the above help functions in three cases. In the first case, a student asked one of his/her classmates to help him/her, without firstly using the globe button offered by the Instruction mode of Onlabs. In the other two cases, the students asked their classmates' help after using the globe button. In all these three cases, the students who were called to help, responded immediately and successfully. Regarding Group A, in three cases, 2 students could not remember the names of the parts of the microscope they had to locate and handle. In Group B one student did not remember the name of a part of the microscope, while in Group C all students knew all the parts. The above results are an indication that the existence of both audio and written help hints in a virtual learning environment enhances the students' ability to memorize the new terminology, converging on the cognitive theory of multimedia learning which argues that learning is optimal when both the visual and auditory channels of memory are used to the same degree (Mayer, 2005; Mayer & Fiorella, 2014).

2nd Phase

Figure 6 presents the results of the students' evaluation in the biology lab, based on the questionnaire. The blue colour of the pies corresponds to the percentage of the "The student performed the step easily" answers out of the total answers in a Group, the orange colour corresponds to the percentage of the "The student performed the step with difficulty" answers out of the total answers in a Group and the grey colour corresponds to the percentage of the "The student was unable to perform the step and asked for help" answers out of the total answers in a Group. Although our sample was quite small, we can have an indication that the multi-user collaborative version of Onlabs helped the Group C to perform easily more steps of the microscopy experiment during the evaluation phase in the biology lab. None of the 4 students in the Group C asked for help in any step of the experiment (Figure 6(c)) and only 6% of the total answers of this Group corresponds to difficulty in performing a step (whereas this percentage was 13% and 11% for Group A and B respectively).

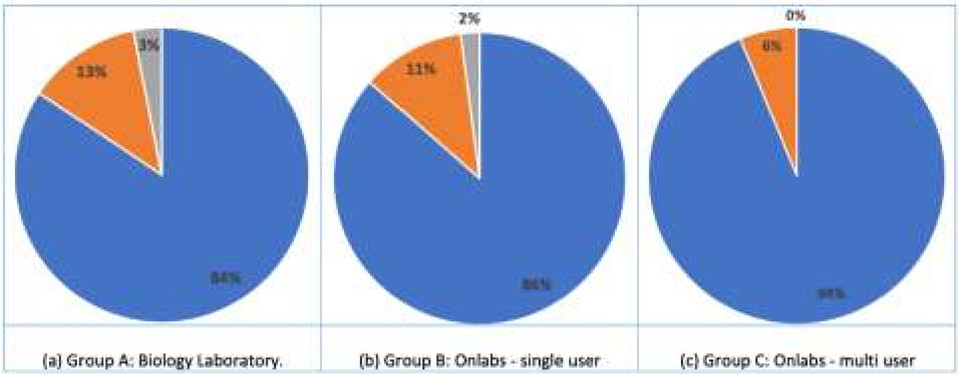

Figure 6: Evaluation of the students' experimental skills in the biology lab.

The data above indicate that the simultaneous presence and the use of collaboration and interaction tools in a virtual learning environment contribute better to the achievement of the learning goals of a biology course compared to the use of a single-user VR software or the participation in the traditional lab tutorial.

5. Conclusions and Future Works

The educational community tries to absorb the impact that technology has on teaching and learning. It is important that the instructors explore its potentials to modernize their teaching methodologies. In this study we attempt to help instructors move towards this direction by presenting an educational tool, the multi-user Onlabs, that can help learners practice on their lab experiments, remotely. The multi-user Onlabs software uses VR technology and simulates the equipment of a biology lab where 4 students perform the microscopy experiment in a collaborative environment. In this study we also demonstrate the results of a preliminary empirical study where three groups of Lyceum trainees are educated in the microscopy experiment by following different learning methodologies. The acquired laboratory skills are finally assessed in the physical biology lab as an attempt to evaluated the followed learning methodology: training in the physical lab by attending the face-to-face lab tutorial, training with the single-user or with the multi-user Onlabs. Our research resulted to some indications that the Group C, that was trained in the microscopy experiment in the virtual collaborative environment of the multi-user Onlabs, where the learners could interact synchronously with other trainees (as it usually happens in a real lab), were better educated in the experiment than Group A, or Group B. During the training, the learners in Group C preferred to ask help from their classmates than using the automated hints offered by the software. This students' behavior indicates that collaboration and communication in a science lab (even if we are referring to a virtual lab) enhance learning and lab performance. Additionally, the learners from Group C could remember the name of all parts of the microscope during the evaluation phase in the physical lab, whereas there was some cases where students from Group A and B could not locate some parts.

The proposed software is a modern, safe and engaging tool that can be used in crisis situations, like the latest pandemic and it holds the promise of substantially reducing the carbon footprint of activities which, to date, rely heavily on transport for on-site practice.Future research could include the replication of the empirical study with a bigger sample. It could also include a scenario where students are fewer than the available instrument. In this case, more than one trainees would need to make use of the same instrument at the same time. Such scenario could generate many research questions about students' interaction in a multi-user virtual environment with shared equipment, and about the development of collaboration and interaction features from a technical point of view. For example, if someone is rotating the aperture knob of the microscope, will someone else be allowed to use the same equipment or not? Or, if someone takes the pipette from someone else's microscoping kit, how will it be recognized and what kind of interaction options might it have? Those and several other questions would naturally come up as an area of further research.

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