Article

Implementation and Evaluation of a Three-Dimensional Virtual Reality Biology Lab versus Conventional Didactic Practices in Lab Experimenting with the Photonic Microscope

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Abstract

This study presents the integration of three different teaching scenarios, during biology laboratory lessons, with the overall aim of exploring the potential predominant effectiveness of teaching and improvement of students' learning, by the use of the three-dimensional virtual reality educational tool Onlabs, versus more traditional didactic practices. A sample of 83, fourth year, undergraduate students of the Primary Education Department of Patras' University in Greece, were equally separated into three cognitively balanced groups to be educated on the light microscopy experiment by three different educational scenarios. Students' conceptual understanding in the domain of microscopy, was evaluated during all learning procedure with Pre and Post tests, whereas their skill to handle properly a real light microscope in the wet biology lab was summatively assessed via a specially designed work sheet. Results of the present study provide evidence in favor of the virtual reality application. © 2019 International Union of Biochemistry and Molecular Biology, 48(1):21–27, 2020.

Keywords: *Science education; instructional video; virtual reality lab; biology laboratory course*

Introduction

The rapid advances of information technology has an enormous impact on education [1, 2]. Technology is a vital tool that improves the students' learning skills [3, 4]. The rate of technological development shows no signs of slowing down and the progressively acquired digital culture strongly affects the construction and distribution of knowledge around the world [5]. In the field of science, the integration of information and communication technologies (ICTs) into teaching and learning procedure has contributed significantly to a better understanding of the different scientific concepts. The educational systems designed decades ago, are no longer appealing to the new generation of students who were born in a digital age where technology dominates everyday's life [6].

Due to the unlimited access to the innumerable applications of this digital world, students have improved their learning capacity through visual and tactile modalities [7]. They process information fundamentally differently from their predecessors [8]. Despite the economic burden, the educational institutions take advantage of technological innovations so as to enrich the conventionally applied learning methods and curriculums. Technological educational tools effectively engage students in the learning procedure as additional materials to the classical learning scenarios, so the contents to be taught, are increasingly supplemented in the classroom with virtual reality technology, videos, etc. [9]. The new proposed learning environments/tools/methods should be assessed in terms of accomplishing the desired

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learning goals or outcomes. In respect to the laboratory experience in biology, it is widely admitted that virtual and augmented reality have shown a great potential in providing essential knowledge and ensuring students' active attendance [10, 11].

Practical laboratory training in natural sciences appears as an even more difficult level of educating students and due to the high costs and time and safety constrains, it is usually preferably removed from the curriculums. Laboratory experimenting is hazardous, acquires expensive laboratory instruments elegant in handling, safety precautions, and strict tutoring. Thus, rather than being an interesting task, sometimes students may feel intense anxiety during the experimental process, and as a result, they are not benefited. The virtual reality educational application Onlabs been designed on the basis of these learning axes, and in this project, it is subjected to a pedagogical evaluation against other, more classical learning methods [12]. Onlabs is developed by an interdisciplinary scientific team of the Hellenic Open University (HOU). It is a three-dimensional (3D) virtual biology laboratory that simulates biology experiments. Distant students of the HOU are familiarized to the virtual lab instruments and equipment by remote interaction. OnLabs can be downloaded at https://sites.google.com/site/onlabseap/download [13].

The main axis of our presented research is the operation of the microscope, the central instrument in a cell biology wet lab. Our aim is to identify and introduce method/s which may assist in instructing, even those who are not directly related to biology, to operate the most essential instrument in a biology lab. More analytically, this study examines whether: (*a*) face-to-face demonstration, or (*b*) a video introduction lab activity, or finally (*c*) a simulated lab activity, would educate most effectively undergraduate students of the Department of Primary Education of Patras' University in Greece, to the lab experiment of light microscopy.

The Participants and the Method

The Participants

In this study, our sample comprised an entire class of 83 fourth year, undergraduate students of the Department of Primary Education of Patras' University, Greece who were enrolled in the "Computers and Education" course. In general, students who attend this course are primarily practicing in computer use, are informed about the developed educational software for primary and secondary education and are educated on technology-assisted teaching and learning.

Our sample was selected with the assumption that it would represent an ideal skill-less and immature audience that brought a zero to minimum prior knowledge on the topic of biology, and furthermore, on the hands-on experience with a photonic microscope. As biology is a fast developing field which increasingly networks with other disciplines (bioinformatics, bioeconomy, biomedical engineering, etc), we expect that raising the potential for the primary schoolteachers to gain basic scientific background with a cell biology wet lab through ICT, will serve as a future expertise science tool to be used toward their students.

The experimental part of our project was supported by: (*a*) two PhD candidates, the first trained in didactics of biology and the second in computing, who have both participated in similar already published studies, (*b*) five PhD tutors, the four of them experienced in teaching laboratory biology courses, and the fifth experienced in assessing educational software, and (*c*) three faculty members with area of expertise biology, educational technology, and artificial intelligence as supervisors of the evolving experimental procedure.

The Experimental Outline

The 83 students were separated in three different groups, with practically equal amount of individuals. Table I gives the structure of the educational scenario followed in this project.

As Table 1 presents, at the first phase (*Introduction in Microscopy*) all students attended a face-to-face tutorial. At the end of the tutorial, a Pre-Test was given in order to set a baseline in the students' understanding on microscopy. Based on the Pre-Test scores an effort was made to divide the class in three cognitively equal groups [14]. Table II presents the mean score for each group. The mean scores are not statistically significant different ($F(2.80) = 0.086$; $p = 0.918 > 0.05$).

After dividing the students into three numerically and cognitively equal groups, the second phase of the scenario was introduced (*Trained on Microscopy*). During this phase a different teaching method was applied to each group:

i. The Conventional Group (C Group) was trained through the conventional didactic model, by simply attending a live demonstration of a microscopy procedure,
ii. The Video Group (V Group) watched a video of the microscopy experiment, and
iii. The Virtual Reality Group (VR Group) entered the Computers and Educational Technology Lab of Patras' University, to be trained in the microscopy via the virtual reality educational tool, Onlabs.

Each one of the above three educational methods lasted 1 hour. Immediately following the second phase, all 83 students filled in a second written test, the Post-Test. In this point our goal was to reassess the knowledge on microscopy, so as to compare the Post-Test scores with the students' scores in the first written test, the Pre-Test. Through the above comparison we evaluated the increase in the learning outcomes due to specific applied teaching method. The Pre and the Post-Test consisted of a limited set of

TABLE I *The experimental outline of the project*

1st Phase (Introduction in Microscopy)—1 hr ($N = 83$)		
1. Attend a face-to-face tutorial on the principals of light microscopy		
2. Fill in the Pre-Test		
3. Division of the 83 students in three cognitive balanced groups based on the Pre-Test scores		
2nd Phase (Trained on Microscopy)—1 hr		
C Group ($N = 30$)	V Group ($N = 29$)	VR Group ($N = 24$)
1. Watch a live demonstration of a light microscopy procedure performed by an experienced tutor	1. Watch an instructional video on a light microscopy procedure	1. Trained on the light microscopy procedure by using the virtual reality lab application
2. Fill in the Post-Test	2. Fill in the Post-Test	2. Fill in the Post-Test
3rd Phase (In the Wet Lab)—0.5 hr		
1. Perform a light microscopy experiment in the wet lab, with a personal light microscope		
2. Fill in a Work Sheet designed to assess the skills on handling a light microscope		

exactly the same 20 multiple choice questions. The questions were carefully designed so as to correlate to the four of the six levels of the revised Bloom's taxonomy that were associated with the following educational goals: remembering, understanding, applying and analyzing [15, 16]. None of the questions corresponded to the higher levels of this taxonomy, that is evaluation and creation, given that our sample consisted of students who were not yet content experts.

Finally, in the third phase (*In the Wet Lab*) all students appeared in the biology wet lab, as part of a pre-scheduled laboratory exercise to perform a complete hands-on microscopy experiment. Each student had exclusively her/his own photonic microscope. Their ability to perform the specific experiment was assessed by the published model presented by the authors in [17]. According to this model the complete microscopy procedure was divided into 22 steps. An example of one of these 22 steps is given in Table III. Simultaneously with the performance of the experiment, the students had to tick each step in a work sheet. Our work sheet included the 13 steps of the experiment, instead of the 22 steps proposed by the initial model. The nine steps of the initial test were skipped, as in our opinion those steps are objectively easy to carry out, they represent a general ability in handling lab equipment and they do not reflect the specific skill of using a microscope. For example, the steps erased were in the context of common sense, such as: "connect the plug of the microscope into the nearest socket."

In parallel with performing each of the 13 experimental steps, the students had to tick on one of the three given options (a), (b) or (c), as presented in Table III.

The Conventional Teaching Method-C Group

The group of students who followed this educational method, passively attended a live demonstration of the complete microscopy procedure from the lab tutor (Conventional group,

TABLE II *Means and standard deviations of the scores in Pre-Test for students in the three groups (C Group stands for Conventional Group, V Group stands for Video Group, and VR Group stands for Virtual Reality Group)*

	C Group	*V Group*	*VR Group*
Pre-Test score	5.5 ± 1.25	5.52 ± 1.39	5.63 ± 1.32

TABLE III *A step from the work sheet designed to assesses students' ability to focus successfully on a specimen using the magnification 4×, 10×, and 40× in a photonic microscope [17]*

"Place the specimen on the stage and stabilize it with the stage clips"
a) I completed the step easily
b) I completed the step on difficulty
c) I could not complete the step by myself

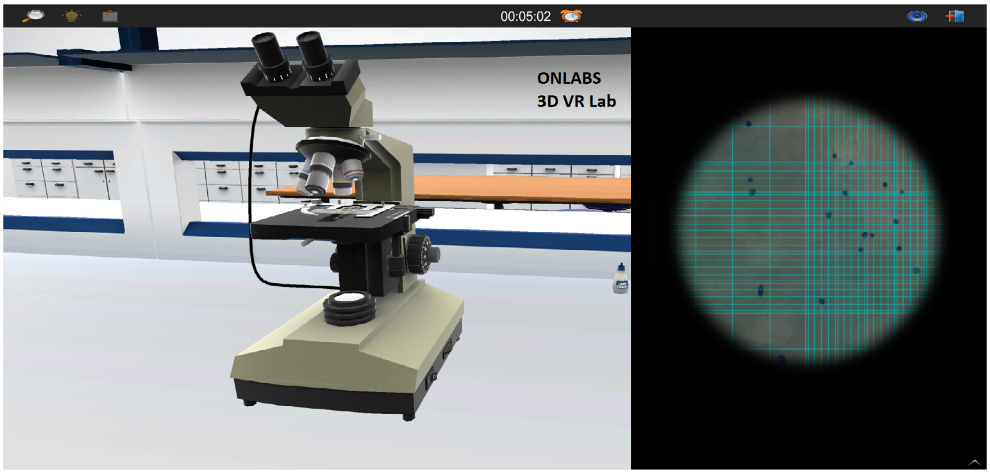

FIG 1 A close-up capture of the three-dimensional virtual reality educational application, Onlabs. The virtualized photonic microscope is adjusted by the user to focus on grid lines of the hemocytometer. [Color figure can be viewed at wileyonlinelibrary.com]

C Group). During this tutorial the teacher used a set of very detailed PowerPoint slides, in order to present the basics on light microscopy. Projected computer images were displayed, but no other interactive means such as Smart Boards were used for this tutorial. Also, a photonic microscope was apparent and parts of the equipment were demonstrated to the classroom.

The Instructional Video Method-V Group

Video has extensively integrated as part of traditional courses in higher education. Toward the educational needs of this study, we videotaped the complete microscopy experiment at the biology lab of the HOU. The video was processed with the Video Editor Camtasia 8 [18] and it is freely available as it is uploaded at https://www.youtube.com/watch?v=FmguLvkKJXY&feature=youtu.be. Within the video streaming there are several pauses where the narrator gives details on the function and on the different parts of the microscope, while at the same time, arrows and many visual effects appear on the screen making the presentation more informative.

The Virtual Reality Educational Method-VR Group

Onlabs is a 3D virtual reality biology lab designed to offer a high level of realism regarding microscopy [19]. Onlabs provides the user with three modes: the *Instruction Mode*, the *Evaluation Mode* and the *Experimentation Mode*. When choosing the Instruction Mode the user performs the microscopy experiment step by step by following instructions. When using the Evaluation Mode, the user conducts the microscopy experiment and at the same time she/he is evaluated for his/her performance. Finally, when using the Experimental Mode the user practices on the experiment without evaluations or instructions.

Upon training with Onlabs, the tutor used the Experimental Mode through a projector screen, and made a demonstration of the microscopy procedure explaining in details the students' queries. After the tutor's demonstration, each student used a personal PC and through the Instruction Mode of Onlabs, performed virtually the microscopy experiment without any further assistance. Fig. 1 represents a screen shot of the virtual environment of Onlabs.

Results

The Shapiro–Wilk test for Normality showed that our data follow the normal distribution ($0.935 < W < 0.969$, $p < 0.05$). Therefore parametric statistical tests were used to detect statistically significant differences between and within the groups. The one way analysis of variance test followed by the Scheffé test as post hoc test and Student's t-test for paired samples were used to detect differences among the scores of the three groups, Pre and Post the applied educational method. Chi-square (χ^2-test) was also used to detect differences in frequencies and percentages concerning the three groups. The respective effect sizes in each analysis were also calculated [20–23].

Statistical Comparisons Between Pre- and Post-Test

Analysis of the Post-Test scores revealed that they were statistically significant higher than the Pre-Test scores in all three groups of students (Table IV). In details, the Post-Test scores of C Group, V Group, and VR Group were statistically significant higher than the corresponding scores in the Pre-Test (C Group: $t = -2.538$; $df = 29$; $p < 0.05$, V Group: $t = -4.353$; $df = 28$; $p < 0.001$, VR Group: $t = -8.823$; $df = 23$; $p < 0.001$). The effect size for the C Group was medium ($d = 0.47$), for the V Group was strong ($d = 0.81$), and for the VR Group was very strong ($d = 1.77$). Thus, we can support that the Conventional teaching method had a moderate effect on the students' score, the Teaching method with

TABLE IV ***Means and standard deviations of students' scores in Pre- and Post-Test***

	C Group (N = 30)	*V Group (N = 29)*	*VR Group (N = 24)*
Pre-Test	5.65 ± 1.25	5.52 ± 1.39	5.63 ± 1.32
Post-Test	6.52 ± 1.31	6.64 ± 1.19	7.39 ± 1.18

Video had a strong effect on the students' score and the Teaching Method with the Virtual Reality Lab had a stronger effect on the students' score. The mean difference was 0.867, 1.121, and 1.754, while there was a total 15.35%, 20.31%, and 31.15% increase between the Pre- and the Post-Test for C, V and VR Group, respectively.

Statistical Comparison of the Post-Tests Among C, V, and VR Groups

The scores of the Post-Tests were statistically significant among the three different groups ($F(2.57) = 3.67$; $p < 0.05$) and the calculated effect size $\eta^2 = 0.08$ was medium. In particular, the Post-Test scores of the VR Group were statistically significant higher than the Post-Test scores of the C Group (mean difference = 0.871, $p < 0.05$). The Post-Test scores of the VR Group were also higher but not statistically significant higher than the Post-Test scores of the V Group (mean difference = 0.749, $p > 0.05$). Finally, the Post-Test scores of the V Group were higher but not statistically significant higher than the Post-Test scores of the C Group (mean difference = 0.121, $p > 0.05$).

Focusing now on each group separately, we present in Table V the percentages of the students that had an increase, a stability or a reduction in their scores. Statistically significant differences among the three groups were derived ($\chi^2 = 22.56$; $df = 4$; $p < 0.05$), with a small effect size ($V = 0.03$), meaning that the effect of the different teaching method on the increase, stability or reduction in students' scores was statistically significant but not too strong. Regarding the C Group, 70% of the students increased their scores between the Pre- and the Post-Test, 6.67% had the same score, whereas 23.33% of the students obtained a lower grade in their Post-Test. Detailed results are also presented in Table V for the V Group where 68.97% of the students increased their scores, 10.34% had a stable score and 20.69% obtain a lower score. In the VR Group, the percentage of students who demonstrated an increase in their test score was statistically significant higher than the percentage of students in the C and V Group. It is noteworthy that within the VR Group none of the students had her/his score dropped. This drop in Post-Test scores indicates that the applied method in the C and V Group did not offer to students' certainty on the obtained knowledge and as a result it is probable that these students followed the strategy of the *lucky guess* while answering the multiple choice questions both in the Pre- and the Post-Test.

TABLE V ***Percentage of students who had their scores increased, stabilized or dropped between the Pre- and the Post-Test, in three groups***

	% of students with increase in their score	*% of students with stability in their score*	*% of students with reduction in their score*
C Group ($N = 30$)	70	6.67	23.33
V Group ($N = 29$)	68.97	10.34	20.69
VR Group ($N = 24$)	91.67	8.33	0

TABLE VI ***The percentage of the answers belonging in each category, for each group***

	1st Category I completed the step easily	*2nd Category I completed the step on difficulty*	*3rd Category I could not complete the step by myself*
% of the total answers in C Group ($N = 390$)	76.92	14.10	8.97
% of the total answers in V Group ($N = 377$)	74.09	18.22	7.69
% of the total answers in VR Group ($N = 312$)	83.40	12.55	4.05

During the third and final phase of this study (In the Wet Lab), all students appeared at the biology lab to perform a real microscopy experiment and to fill in the work sheet. As it is previously mentioned, the work sheet consisted of 13 different steps and three possible answer-categories for each step (Table VI). As a result, from the C Group ($N = 30$) we took $30 \times 13 = 390$ answers, from the V Group ($N = 29$) we received $29 \times 13 = 377$ answers, and from the VR Group ($N = 24$) we received $24 \times 13 = 312$ answers.

As Table VI indicates, only 4.05% of the total amount of answers that were given by the VR Group students belonged to the third category (incompetence to complete an experimental step), whereas among C Group and the V Group this percentage reaches the 8.87% and the 7.69%, respectively.

Statistically significant differences among the three groups were derived comparing data in Table VI ($\chi^2 = 19.25$; $df = 4$, $p < 0.05$) with a small effect size ($V = 0.08$) meaning that the effect of the different teaching method on the students' ability to perform the steps of the experiment on their own, is not too strong.

Discussion

Multiple studies have shown that video, which has been extensively used as an educational tool, can be highly effective. Video is a much richer medium than text or audio as with its moving pictures expands students' understanding of content [24] and promotes observational learning [25]. In Natural Sciences, videos can familiarize students with experiments that can be hazardous, expensive, difficult, or simply impractical to perform in real labs [26].

More recently, virtual reality technology is increasingly being used in educational contexts as an attempt to improve higher education [10]. Many studies show that simulations can be a very promising and affordable tool for learning and instruction [27, 28], especially for users who are not aware on information technologies [29]. Virtual laboratories have overall positive effects on students' cognitive load, skills development and motivation. In refs. [6, 11] the authors proved that in medical developmental biology when a virtual teaching method is combined with the traditional one, it promotes effective student learning. Claiming that knowledge includes two closely related components, content, and skills, students attending science courses must not only obtain conceptual knowledge of specific topics, but also should gain specific practical laboratory skills [30]. A key aspect to obtain these skills is to practice, to repeatedly perform an experiment instead of passively watching a demonstration or passively listening to the instructor [31]. In addition, like all modern ICT educational applications, virtual applications have general features that can support constructive learning [32], while they are very effective in dynamically engaging learners in the learning process [33]. More specifically, when referring to biology, new ICT applications such virtual labs, contribute to the teaching methods so that educators can overcome the educational problems that arise from the complexity of this course.

Conclusions

Technological and educational tools, like videos and virtual labs, are often incorporated in the learning process as self-paced learning tools that help students acquire confident knowledge of science and laboratory skills. Among the strategic goals of higher education institutions is to communicate the knowledge and promote their students to acquire high standard skills. Internal processes for evaluating innovative teaching methods are particularly important. Systematic evaluation leads to continuous improvement and ensures quality teaching. This study aimed to illustrate the different outcomes between innovating learning tools and more traditional teaching methods, in an effort to emphasize on the effectiveness of virtual reality labs subjected to science practical learning. Thus, we compared and evaluated three different teaching methods regarding the photonic microscopy experiment. Statistical elaboration of the study results, provide evidence in favor of laboratory simulations. In more details, the VR Group of students who were trained in microscopy via a virtual biology lab, Onlabs, strengthened their grasp of the concepts and increased their initial conceptual knowledge by 31.15% in comparison with the C Group of students who were trained through the conventional face-to-face tutorial or the video method (V Group) and increased their knowledge by 15.35% and 20.31%, respectively. Further results of this study indicated that the conventional and the video teaching method did not provide students with confident knowledge on the subject, as 23.33% of the students in C Group and 20.69% of the students in V Group had their score reduced in their second written test. On the other hand 8.83% of the students who used the virtual lab kept their test scores stable, while no score reductions were observed within the same group. Concerning the gained experimental skills, the study results showed that on average, students who had the virtual lab experience became more capable in handling the sensitive and expensive photonic microscope than their fellow students, as during the real microscopy experiment in the biology lab, they asked for help almost two times less than their fellow students (4.05% for the VR Group vs 8.97% and 7.69% for the C and V Group, respectively).

Summarizing, our results provided an initial proof that virtual laboratory simulations are very promising tools in educating microscopy users, in terms of how to treat and operate in safety a microscope, comparing to more traditional methods. The design and the implementation of a new study, where students more related to biology than primary education students, will practice via Onlabs more complex experiments, such as protein electrophoresis or DNA extraction, belong to our future research plans, since we are already close to finalizing the respective piece of software. With the certain assumption that physical labs offer critical ingredients in lab learning, there is a need for universities to become attuned to this new need of students to learn science through technological tools, and design educational scenarios that consist, at least partially, of activities that involve simulations and other technological innovations.

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