Design, Implementation, and Evaluation of Online Bioinformatics and Neuroinformatics Labs

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Spyridon Doukakis[1(✉)], Aristidis G. Vrahatis[1], Themis Exarchos[1],
Maria Hadjinicolaou[2], Panagiotis Vlamos[1], Chrystalla Mouza[3]
[1]Ionian University, Corfu, Greece
[2]Hellenic Open University, Patras, Greece
[3]University of Illinois Urbana-Champaign, Champaign and Urbana, USA
sdoukakis@ionio.gr

Abstract—In recent years, online laboratories have become highly integrated into the educational process due to the development of distance learning tools as well as circumstances associated with the Covid-19 pandemic. As part of a master's degree program in bioinformatics and neuroinformatics, in the academic years 2020–2021 and 2021–2022, the mandatory module "Laboratory Education (LE)" included 9 labs which transitioned to online delivery. A questionnaire was administered to all participants examining their self-reported learning as well as their satisfaction with each lab, the educational material associated with each lab, as well as the facilitator in each lab. A total of 73 postgraduate students completed the questionnaire. According to the results, the overall satisfaction from each laboratory ranged from 3.94 to 4.49/5.00. Furthermore, there is a variety of values in self-reported learning ranging from 23 to 50/50. Finally, although 7 out of 10 students indicated they are satisfied with the distance structure of LE, 8 out of 10 say they prefer LE to be carried out with a physical presence in the labs.

Keywords—online labs, virtual labs, remote labs, bioinformatics, neuroinformatics, self-reported learning, postgraduate students, satisfaction

1 Introduction

Bioinformatics and Neuroinformatics are fast growing scientific sectors, attracting large investments, and offering excellent employment opportunities to graduates. In fact, postgraduate studies in Bioinformatics and Neuroinformatics offer high career prospects in many innovative and pioneering scientific fields [1]. In addition, postgraduate studies have the potential to engage students with research in these important scientific fields.

Laboratory experiences offer an added value to the education of students in Bioinformatics and Neuroinformatics and are usually part of the academic curriculum [2]. Specifically, Laboratory experiences are valuable because they allow students to learn about the scientific method, including experimental design, data collection and analysis as well as ways of using data to draw conclusions. Thus, gaining laboratory experience is a necessary component of postgraduate programs in these fields, as they help students develop their research skills while simultaneously preparing them for the labor market [3].

The Master's Degree Programme "Bioinformatics and Neuroinformatics" which is offered by the Hellenic Open University in collaboration with Ionian University focuses explicitly on preparing graduates for careers in bioinformatics and neuroinformatics. Specifically the program has three inter-related objectives: a) promote the scientific knowledge and development of primary scientific research in the fields of biomathematics (applied mathematics, modelling and simulation of systems), bioinformatics (genomics, proteomics, biomarker discovery, drug design, systems biology, programming languages for biology), computational biology, neuroinformatics and neurosciences (biomedical signal and image analysis, biomedical data processing, knowledge mining, development of algorithms); b) provide high-level training and expertise in research methodology, including conducting and analyzing clinical studies, processing and interpreting biological data, designing applications for decision making, developing models for diseases' prognosis and diagnosis, and engaging in meta-analysis of biomedical data; and c) prepare qualified graduates for successful careers in both academic and research environments, as well as in biotechnology companies, pharmaceutical industries or computing and research companies, both nationally and internationally. In addition to coursework, the program is reinforced with laboratory education, which is open to all students after completion of the first semester of studies. Laboratory education ("Lab Education" from now on) is compulsory, is not weighted by grades, and requires physical presence at the Laboratory of Bioinformatics and Human Electrophysiology at the Ionian University (BiHELab).

However, the sudden shift to online education due to the pandemic has resulted in the need to adapt labs for virtual delivery. In this context, "Lab Education" for the academic years 2020–2021 and 2021–2022 took place online. In this study, we first present the framework and content of "Lab Education" and how it was delivered in the academic years 2020–2021 and 2021–2022. We subsequently explore students' a) satisfaction concerning the activities within each lab, b) self-reported learning from each lab, c) satisfaction concerning the equipment of each lab, d) satisfaction concerning the material provided for each lab, and e) satisfaction concerning the facilitators of each lab. Finally, we present the findings from this work, limitations of the research, and conclusions.

2 Lab Education

2.1 Bioinformatics and neuroinformatics principles

The online "Lab Education" of the master's degree program "Bioinformatics and Neuroinformatics" lasted ten (10) days. Specifically, "Lab Education" included a total of nine (9) labs as well as a special session related to entrepreneurship in Bioinformatics. The equipment of the Bioinformatics and Human Electrophysiology

Laboratory at the Ionian University was used for the labs. The duration of each lab was approximately 4 hours.

The activities associated with each of the 9 labs focused on bioinformatics and neuroinformatics topics. More specifically, *Lab 1* was concerned with the detection of antigenic epitopes in cytological smears, recognizing the application of automated methods for the detection of antigenic epitopes in cytological smears, and the evaluation of the nuclear or cytoplasmic expression of the applied antibodies at the cellular level. *Lab 2* focused on determining the principles of photonic microscopy using inverted fluorescence microscopy. In *Lab 3* students used a particle sizer to evaluate the Single Particle Optical Sizing method for measuring the size of a large number of particles and construct the actual particle size distribution in a mixture. In *Lab 4*, students worked with databases and performed high-scale data analysis using supervised and unsupervised learning methods. In *Lab 5*, students had the opportunity to study and analyze protein tertiary structures using appropriate libraries and online databases. In *Lab 6*, students used an electronic microscope with a built-in chemical analyzer, to identify the principles of electronic microscopy. Then, in *Lab 7* students utilized a real-time Polymerase Chain Reaction thermal cycler, to explain real-time polymerase chain reaction and techniques for analyzing its results. In *Lab 8*, students utilized behavioral analysis software, electroencephalography (EEG), and biomarkers recording equipment in the context of neuroeducation and neuromarketing topics. Finally, *Lab 9* focused on databases and bioinformatics tools, to find homology and multiple alignments and use tools for in silico protein analysis.

Lab Education concluded with a session on "Entrepreneurship in bioinformatics and neuroinformatics, Career prospects". Table 1 presents the labs, equipment used, description of activities, and expected learning outcomes.

Table 1. Labs Education

Lab	Equipment	Description	Skills Learned
Lab 1: Detection of antigenic epitopes in cytological smears.	Automated immunohistochemistry (immunocytochemistry) machine for the detection of antigenic epitopes, microscope with accompanying equipment for image evaluation, processing, and storage.	Application of automated methods for the detection of antigenic epitopes in cytological smears and the evaluation of the nuclear or cytoplasmic expression of the applied antibodies at the cellular level.	Use of immunocytochemistry for research, diagnostic and therapeutic purposes.
Lab 2: Photonic microscopy.	Full inverted fluorescence microscope. Complete system for acquisition and analysis of imaging data type easyRatioPro.	Basic principles of photonic microscopy.	Proper use of the instrument; Collection and observation of microscopic organisms; Observation of peripheral blood.

(Continued)

Table 1. Labs Education *(Continued)*

Lab	Equipment	Description	Skills Learned
Lab 3: Particle Sizing Systems AccuSizer 780SIS.	Single Particle Optical Sizing System.	Method for measuring the size of a large number of particles, one at a time, and constructing the true particle size distribution (PSD) in a mixture.	Compare methods for measuring the size of a large number of particles.
Lab 4: High-scale molecular biology data analysis using supervised and unsupervised learning methods.	Weka and Matlab Software.	Data mining and analysis. Data preprocessing. Contribution of unsupervised learning with appropriate data.	Develop classification and prediction models; Generate data from molecular biology; Develop Clustering and Visualization Algorithms.
Lab 5: Analysis of tertiary protein structures.	Bio3D library, R and Rstudio.	Understanding and analysis of protein tertiary structures.	Predict protein structure using online methods; Evaluate protein structures.
Lab 6: Electronic microscope and online tools.	Table electronic microscope with built-in chemical analyzer EDS.	Basic principles of electronic microscope and its applications.	Proper use of the instrument; Analysis of samples.
Lab 7: Real-Time PCR – DNA amplification.	Real-time PCR thermal cycler C1000 Touch thermal cycler chassis.	Basic principles of real-time polymerase chain reaction and techniques for analyzing its results.	Identifying how to amplify specific regions of the genetic material; Correlate DNA changes with the diagnosis of pathological conditions.
Lab 8: Behavioral analysis software.	Observer XT and FaceReader, BeneVision N22/N19, Mindray.	Using observer and face recognition software and monitor of observing subjects.	Identifying how behavioral analysis takes place using software and hardware.
Lab 9: Databases and Bioinformatics Tools.	–	Nucleotide, amino acids, biological molecules. Bioinformatics databases for DNA and RNA.	Operate basic bioinformatics tools for homology finding and multiple alignments; Use tools for in silico protein analysis.
Entrepreneurship in bioinformatics and neuroinformatics, Career prospects.	Entrepreneurship opportunities in bioinformatics and neuroinformatics.	Recognize entrepreneurship opportunities in bioinformatics and neuroinformatics.	–

2.2 Pedagogy of online labs

Lab activities empower students to learn and practice, while simultaneously increasing motivation and leading to a positive attitude towards the course [3]. Despite the promise of lab education, the cost of the lab equipment is usually high. Due to limitations in the availability of equipment, traditionally there was a need for students to share the equipment while conducting physical labs. Further, to address resource constraints, each group performed the experiments only once. The Covid-19 pandemic made it necessary to replace traditional labs with virtual labs [4], helping address some of the limitations associated with physical labs. Online laboratories, for instance, are not nearly as costly to run compared to traditional laboratories [6]. Therefore, the shift to virtual delivery, addressed issues around the availability of equipment and provided opportunities to perform the lab multiple times. Further, virtual labs helped eliminate students' fear of making mistakes offering opportunities to repeat as needed. Finally, virtual labs facilitated independent learning and provided flexibility to students in terms of space and time, particularly for students who had difficulties commuting and attending a traditional lab away from their homes [8].

In the context of this work, the design of the online labs was consistent with principles of distance education and efforts to strengthen self-regulated learning [5]. The delivery of the online labs was facilitated through the learning management system students used in their coursework. A combination of synchronous and asynchronous learning activities was used to achieve the goals. Specifically, emphasis was placed on the educational process and the pedagogical use of the lab equipment. During the educational design, clear learning objectives were determined that guided the development of educational material and interactive lab activities. The educational material followed pedagogical specifications to attract student interest and effectively support them in the learning process, while conducting the labs independently. This approach was successful by matching the theoretical training students had already acquired from the modules they had completed with the laboratory training they were offered. At the same time, the educational material provided opportunities for active participation, formative feedback, and self-evaluation. From a design point of view, a key consideration also focused on ensuring that labs were designed to be equitable for all, regarding the means and labs' objectives [7].

3 Research approach

A quantitative research design was employed to examine students' perceptions of the virtual labs. Specifically, upon completion of the laboratory exercises associated with the 9 labs presented above, including the special session on entrepreneurship, a questionnaire was sent to all students who participated in "Lab Education". The questionnaire was developed by the research team and was aligned with dimensions of high quality lab education. Specifically, the following five quality dimensions (criteria) were defined and used for each lab (See Figure 1).

1. Students' satisfaction concerning the educational activities within each lab;
2. Students' self-reported learning from each lab;

3. Students' satisfaction concerning the equipment of each lab;
4. Students' satisfaction concerning the material made available to them from each lab;
5. Students' satisfaction concerning the facilitators of each lab;
6. Students' overall satisfaction with each lab considering all the above.

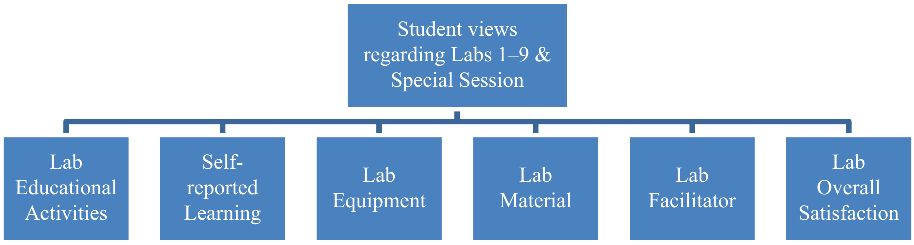

Fig. 1. Structure of quality dimensions

Moreover, the questionnaire included questions regarding student satisfaction concerning a) their interaction in the Labs; b) the educational approaches (e.g., constructivist) that were used in Labs; c) the design of "Lab Education" (e.g., tools and resources that were used); and d) time spent studying during the "Lab Education" program. Finally, the questionnaire asked students to indicate their overall satisfaction with the distance "Lab Education" program as a whole and register their preference between physical and virtual labs. Specifically, the online questionnaire included five parts:

1. Instructions on how to fill out the questionnaire.
2. Likert scale questions focusing on the five quality dimensions of virtual labs. For this purpose, a five-point Likert scale was used which ranged from "Totally disagree" to "Totally agree" or "Totally satisfied" to "Totally dissatisfied".
3. Questions concerning the virtual labs and the distance learning approach.
4. Demographic data.
5. An open-ended question at the end of the questionnaire where students could make suggestions concerning lab improvement. The results from this question are not presented in this work.

The questionnaire was distributed to all 98 students who completed the labs during the academic years 2020–2021 and 2021–2022. The questionnaire was administered each academic year, after the completion of the "Lab Education". A total of 73 students fully completed the questionnaire, representing a return rate of 74%. Of those, 40 participants (56%) were males, and 29 (40%) were females. Three respondents chose not to respond to the gender question. The majority of the respondents, 47 (65.0%), had no previous experience with laboratory education. Further, 55 (76%) did not experience technical problems with online labs. Table 2 presents the profile of our sample.

Table 2. Students' demographic profile

Demographic	Description	No	Percentage
Gender	Male	40	56%
	Female	29	40%
Previous experience with Lab Education	Yes	25	35%
	No	47	65%
Experienced technical problems	Yes	17	24%
	No	55	76%

Data were analyzed using descriptive and inductive methods. Additionally, we employed the capabilities of statistics and machine learning to mine our data. Specifically, we applied dimensionality reduction techniques to reduce the complexity of our data, offering visualization schemes that facilitated more efficient data analysis. Towards this end, we applied the principal component analysis (PCA) [9] and the t-distributed stochastic neighbor embedding (tSNE) method [10] in examining the data. Both techniques transform the initial data dimensionality into a lower-dimensional data space while preserving the pairwise sample distances as much as possible. More specifically, PCA projects the initial data onto a new subspace keeping most of the variance among the data points. The tSNE is an extension of the stochastic neighbor embedding method trying to transform the pairwise data similarities into joint probabilities.

4 Results

4.1 Student satisfaction and self-reported learning

Based on the descriptive statistics, the mean of students' satisfaction was measured. Means ranged from 3.92/5.00 to 4.58/5.00. In particular, the satisfaction per laboratory (Figure 2) was measured. The results show that the Data Analysis (Lab 4) and PCR Labs (Lab 7) offered students the highest level of satisfaction (4.40/5.00). In contrast, the AccuSizer Lab (Lab 3) had the lowest satisfaction score (3.92/5.00), followed by the Photonic Lab (Lab 2) (4.14/5.00).

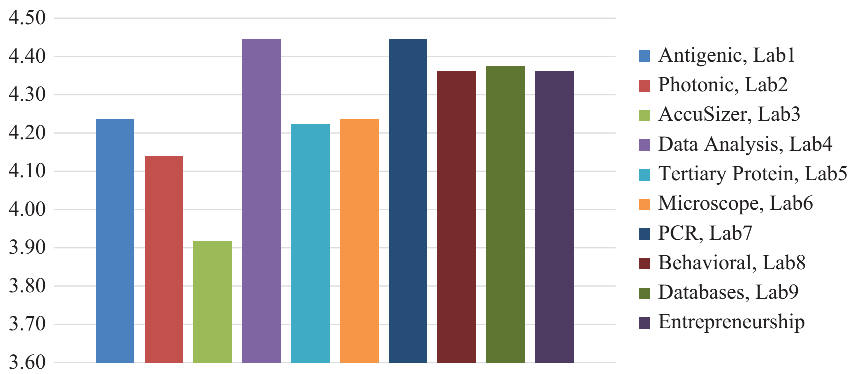

Fig. 2. Mean of students' satisfaction with each Lab

Concerning self-reported learning from each lab, (Figure 3), students indicated that they received more satisfaction with knowledge acquired from the Data Analysis Lab (Lab 4) (4.36/5.00) followed by the DataBases Lab (Lab 9) (4.33/5.00). In contrast, the AccuSizer Lab (Lab 3) had the lowest level of satisfaction with knowledge acquired (3.92/5.00), followed by the Photonic Lab (Lab 2) (4.01/5.00).

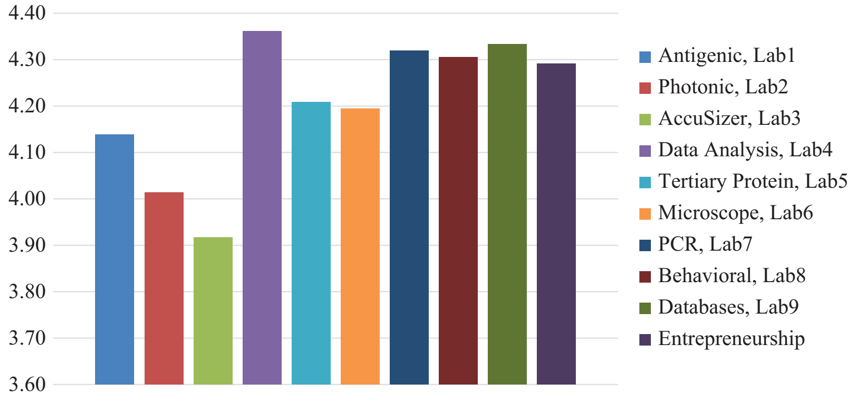

Fig. 3. Mean of students' satisfaction with knowledge acquired in each Lab

Regarding the equipment of each laboratory (Figure 4), the two labs with the highest satisfaction scores were the Databases Lab (Lab 9) (4.40/5.00) and Data Analysis Lab (Lab 4) (4.35/5.00) which are the two labs with no-physical equipment at the Laboratory of Bioinformatics and Human Electrophysiology at Ionian University. The only equipment required for these labs is a computer and the corresponding software, which students also have on their digital devices. The lowest satisfaction scores were associated with the equipment of the Photonic Lab (Lab 2) (4.01/5.00), followed by the AccuSizer Lab (Lab 3) (4.04/5.00). The special session on entrepreneurship had no equipment because the facilitators simply gave a lecture and answered questions.

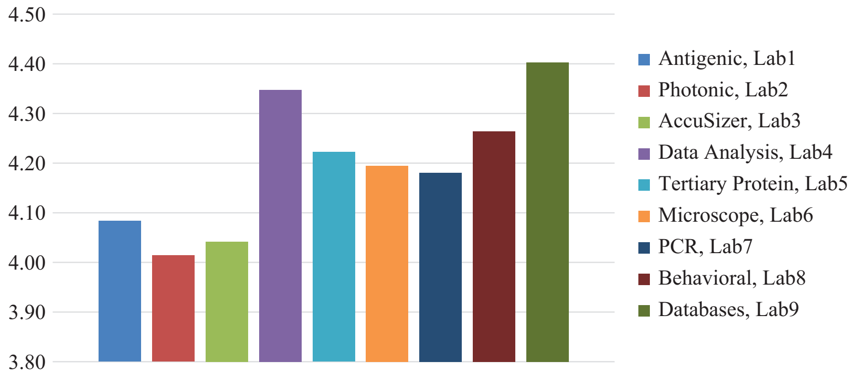

Fig. 4. Mean of students' satisfaction with equipment in each Lab

Regarding the materials students were provided for each laboratory (Figure 5), Databases Lab (Lab 9) (4.40/5.00) and Data Analysis Lab (lab 4) (4.35/5.00) offered students the highest satisfaction. In contrast, the AccuSizer Lab (Lab 2) had the lowest level of satisfaction (3.97/5.00), followed by the Photonic Lab (Lab 2) (4.07/5.00).

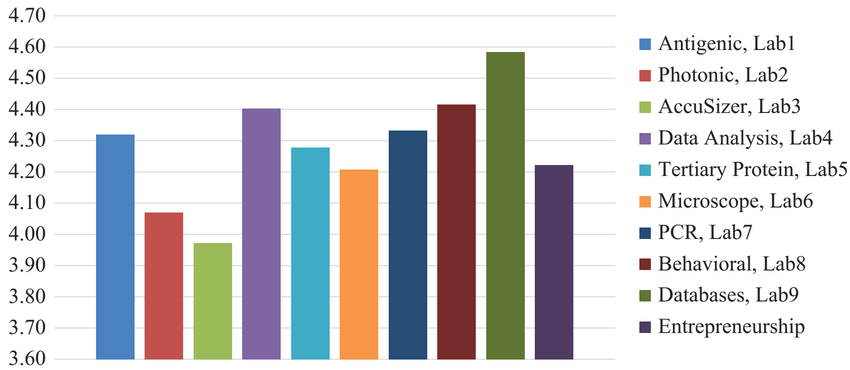

Fig. 5. Mean of students' satisfaction with material in each Lab

Regarding the facilitator in each lab (Figure 6), students indicated more satisfaction with the facilitators in the Behavioral Analysis Lab (Lab 8) (4.58/5.00) followed by the DataBases Lab (Lab 9) (4.51/5.00). In contrast, students reported the least satisfaction with the AccuSizer Lab (Lab 3) (4.25/5.00), followed by the Photonic Lab (Lab 2) (4.31/5.00).

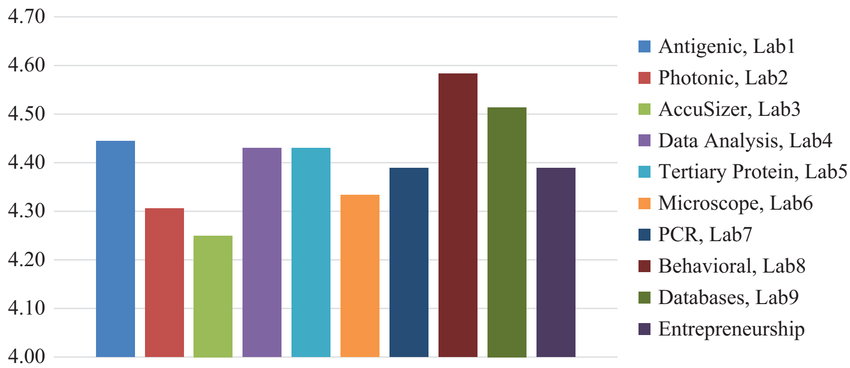

Fig. 6. Mean of students' satisfaction with facilitator in each Lab

Finally, the students' overall satisfaction with each lab is presented in Figure 7. The boxplots show the overall satisfaction of all participants for each lab. As shown in Figure 7, most of the participants rated all the Labs with a high grade. The Entrepreneurship special session had the highest score (4.49/5.00). This lab was unique in that it provided information to students about the labor market and successful startups in the biomedical industry. Given widespread concerns among students about their future academic and employment prospects, this session helped introduce students to future opportunities in their fields. The Databases Lab (Lab 9) also enjoyed high satisfaction while (4.42/5.00) the AccuSizer Lab (Lab 2) demonstrated the lowest level of overall satisfaction (3.94/5.00) followed by the Microscope Lab (Lab 6) (4.11/5.00).

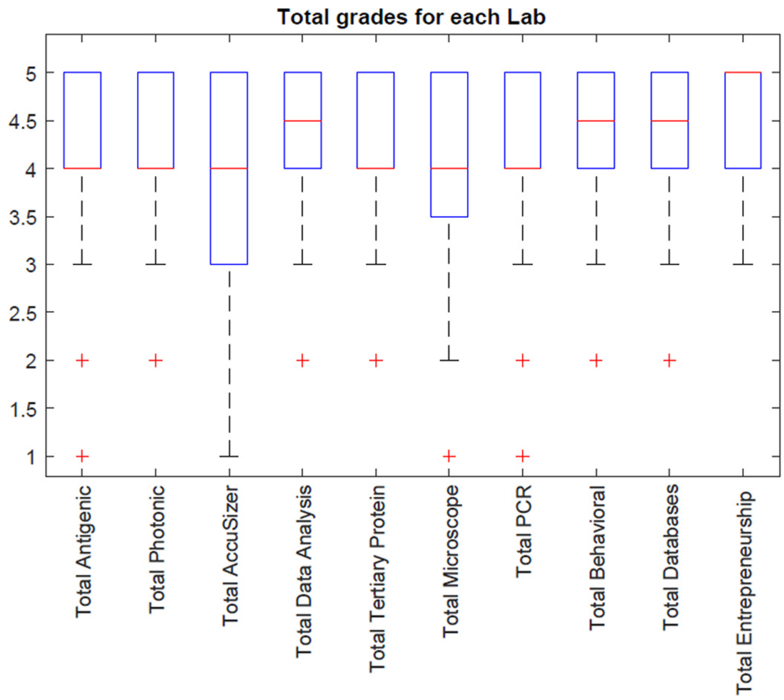

Fig. 7. Boxplot with students' overall satisfaction with each Lab

In addition to recording their satisfaction to specific lab dimensions, students were also asked to indicate their satisfaction concerning a) their interaction in the Labs; b) the educational approaches (e.g., constructivist) that were used in Labs; and c) the design of the "Lab Education" (e.g., tools and resources that were used). Results are presented in Table 3.

Table 3. Students' satisfaction with the distance education approach

Satisfaction Concerning	Description	No	Percentage
Interaction in the Labs	Satisfied	46	63.89%
	Neutral	15	15.28%
	Dissatisfied	11	20.83%
Educational approaches used in Labs	Satisfied	44	61.11%
	Neutral	17	23.61%
	Dissatisfied	11	15.28%
Design of the "Lab Education"	Satisfied	59	81.94%
	Neutral	9	12.50%
	Dissatisfied	4	5.56%

As noted, an additional question focused on how frequently students studied during "Lab Education". The results are presented in Figure 8. The majority of students, 41 students (58.33%) did not report studying, or studied just 1 or 2 times during the 10 days of the "Lab Education".

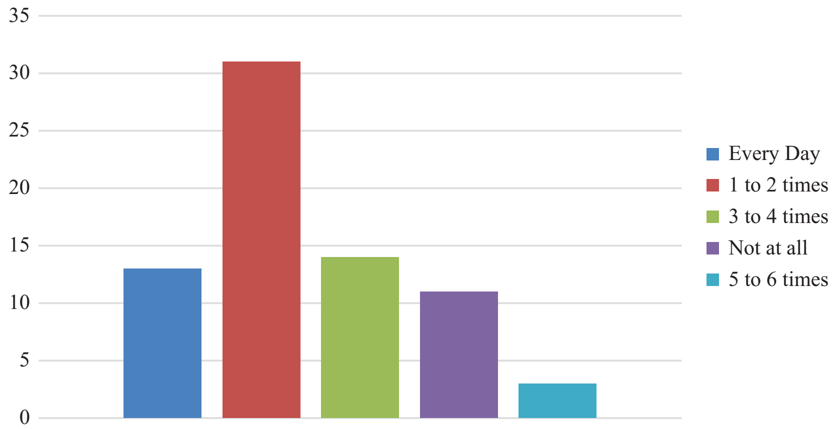

Fig. 8. How often did the students study during "Lab Education"?

4.2 Overall satisfaction and preference between physical and virtual labs

The two last questions concerned students' overall satisfaction with the "Lab Education" program as a whole and their views between online and physical labs.

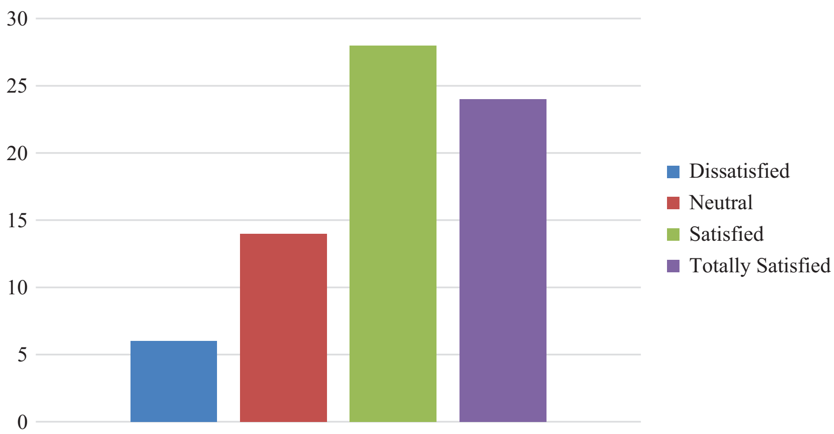

Fig. 9. Students' overall satisfaction concerning the "Lab Education" program

As shown on Figure 9, 7 out of 10 students, (72.22%) declared that they are satisfied with the "Lab Education" program. Importantly, no student declared that was totally dissatisfied. Nonetheless, 8 out of 10 (79%) students declared that they preferred labs with physical presence instead of virtual labs (Figure 10).

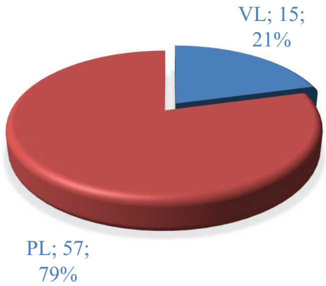

Fig. 10. Students' preference concerning virtual labs (VL) or labs with a physical presence (PL)

Additionally, the correlation among the students' overall satisfaction for all Laboratory pairs is highlighted below (see Figure 11), offering noteworthy results. The pairwise linear correlation coefficient between each pair of labs is utilized, while the values 1–10 in the heatmap correspond to the respective Lab 1–Lab 9 and the special session on entrepreneurship. The strongest correlation is observed between Lab 1–Lab 2, and Lab 6–Lab 2, while the lowest, is observed between Lab 4–Lab 7 and Lab 4–Lab 10.

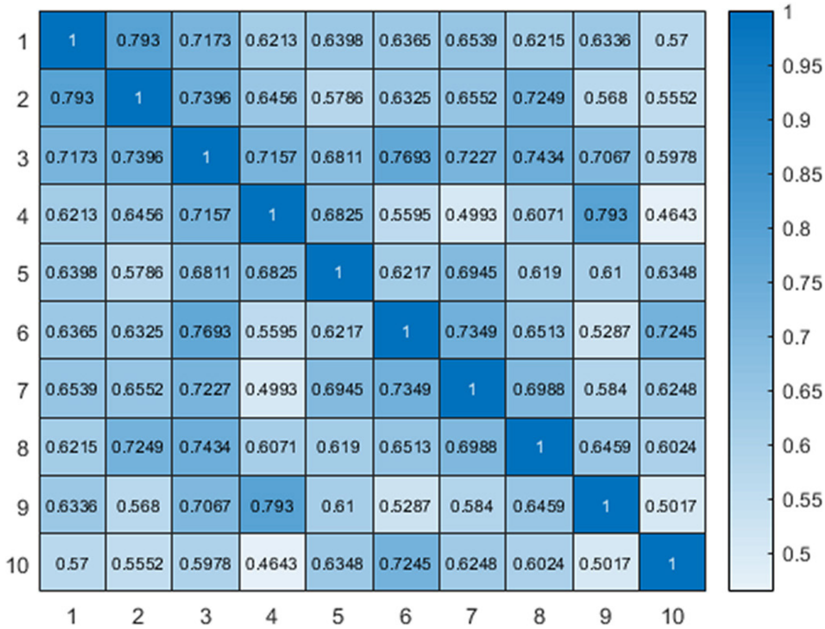

Fig. 11. Heatmap with the correlation among the students' overall satisfaction for all Laboratory pairs

With the application of the principal component analysis (PCA) [8] and the t-distributed stochastic neighbor embedding (tSNE) method [9], we tried to mine knowledge regarding the impact of gender and the previous laboratory experience on students' answers. Using two well-established dimensionality reduction algorithms, we reduced the

60-dimensional space (6 questions for 10 Labs) to a 2-dimensional space (see Figures 12 and 13), offering a visualization framework by coloring each student (circle shape) with his/her gender and previous laboratory experience. The visualization schemes show that both classes are not separable. Hence, the students' answers do not differ significantly according to their identified gender or previous laboratory experience.

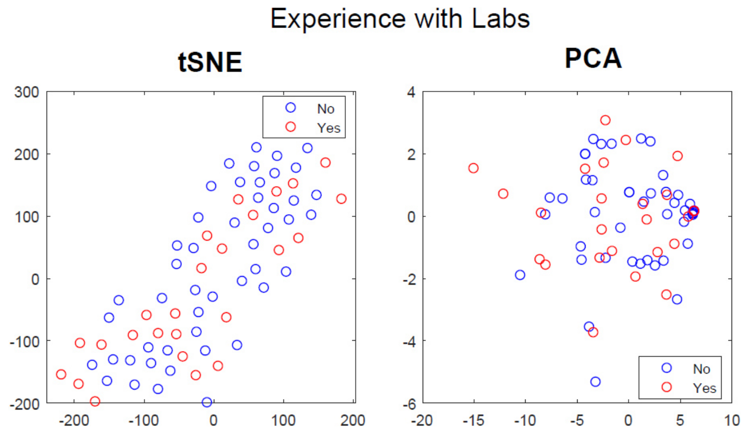

Fig. 12. 2D Visualizations with the laboratory experience impact all students' answers using the tSNE and PCA dimensionality reduction methods

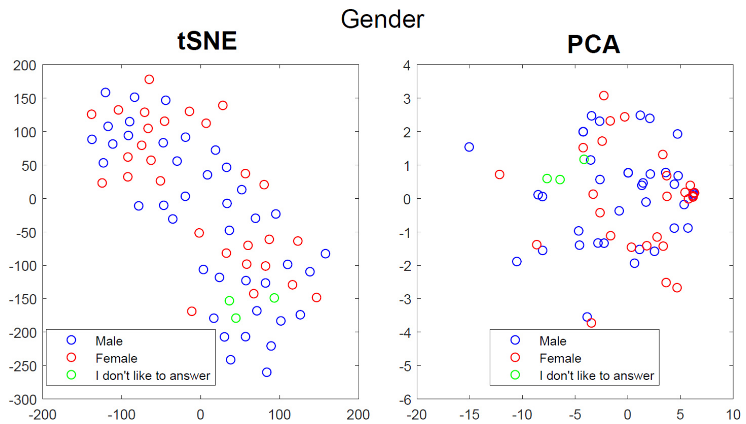

Fig. 13. 2D Visualizations with the gender impact in all students' answers using the tSNE and PCA dimensionality reduction methods

5 Discussion

In this research, we presented the "Lab Education" module of the Master's Degree Programme in "Bioinformatics and Neuroinformatics" which is offered by the Hellenic Open University in collaboration with Ionian University in Greece. Moreover, we examined students' self-reported learning from each lab as well as satisfaction related to the educational activities, the equipment of each lab, the material made available for each lab, and the facilitators of each lab. Additionally, we examined overall satisfaction with the "Lab Education" component of the program and student preferences regarding physical versus virtual labs. Finally, we correlated these results with demographic data and questions regarding the "Lab Education" module.

Students' overall satisfaction concerning each lab was high, as the mean ranged from 3.94/5.00 to 4.49/5.00. Additionally, the total satisfaction concerning the "Lab Education" program as a whole was also high as 7 out of 10 students were satisfied with it. Nonetheless, 8 out of 10 students indicated that they would prefer to be in the laboratory with physical presence during the lab exercises. This finding is not surprising as this was students' first exposure to virtual labs. It is possible that this finding is related to the applied orientation of "Lab Education". "Lab Education" included several experiments and literature indicates that students have difficulties with performing experiments in virtual environments [8, 11]. The majority of the students expressed preference in completing the experiments/exercises in a laboratory with a physical presence. The high satisfaction rate, however, shows that students can cope with a combination of labs, with a physical and online presence.

Findings also indicated that no statistical differences were observed between gender, first-level undergraduate degree, overall satisfaction with the "Lab Education", previous experience with laboratories, and all other variables of the survey. This finding indicates that the virtual "Lab Education" has the potential to reach all students regardless of gender or background knowledge. This finding is noteworthy because the Master's Degree Programme in "Bioinformatics and Neuroinformatics" enrolls students from different undergraduate majors (biologists, computer scientists, mathematicians, clinicians, etc.). Thus, results indicate that the program has the potential to reach students from various backgrounds.

"Lab Education" included a variety of equipment (hardware and software) to carry out the experiments. Some labs had exercises that needed a computer (students had their own device) and free and open software [12, 13], while others had only special equipment without any software. This feature had an impact on both student satisfaction and self-reported learning [14, 15]. Specifically, laboratory topics that did not include biological experiments documented higher self-reported learning and students indicated a high degree of satisfaction. On the contrary, specific laboratory exercises (for example microscopes and biological analyses) received lower satisfaction scores. This finding is likely related to student preference for physical labs and the need to perform the experiment on their own instead of just attending a demonstration of it.

As a final note, it is important to mention, that there are some limitations of this research that should be considered. First, the research was conducted on a module of a specific Master's Programme in Bioinformatics and Neuroinformatics, which meant that the results cannot be generalized to other relevant contexts. Secondly, the students were not divided into groups according to their background characteristics. Lab support from the facilitator was provided in accordance to the principles of differentiated instruction, which may have varied across facilitators. Thirdly, the sample is relatively small, so results should be treated with caution.

6 Conclusions

The goal of this research was to examine student perceptions regarding the "Lab Education" module of the Master Programme in Bioinformatics and Neuroinformatics, which was to take place with physical presence, but due to the Covid-19 restrictions, transitioned to online delivery. Results indicated high students' satisfaction with the program, the facilitators, and the components (equipment, material) of the lab module. Students also declared positive self-reported learning outcomes.

Despite students' high satisfaction, a very large number of students (8 out of 10) stated that they prefer "Lab Education" with physical presence in the laboratories, which highlights that these online laboratories require further design and teaching techniques, that will allow students a more authentic remote experience. This finding merits further research so that students can experience and take part in laboratory education from their own space, using appropriate digital technologies. This approach will enable students to feel confident that they participate in a laboratory environment that enhances their knowledge and understanding, their practical skills, their perception, their analytical skills, and their social and scientific communication with other students and researchers.

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8 Authors

Dr. Spyridon Doukakis is a faculty member of the Bioinformatics and Human Electrophysiology Lab at the Department of Informatics at Ionian University, 7 Tsirigoti Square, 49100, in Corfu, Greece. His main research interests include Computing Education, Educational Neuroscience, Distance Learning, and Knowledge Transformation (email: sdoukakis@ionio.gr).

Dr. Aristidis G. Vrahatis is a faculty member of the Bioinformatics and Human Electrophysiology Lab at the Department of Informatics at Ionian University, 7 Tsirigoti Square, 49100, in Corfu, Greece. His main research interests include Biomedical Data Mining, Pattern Recognition, and High-Dimensional Data Analysis (email: aris.vrahatis@ionio.gr).

Dr. Themis Exarchos holds an Engineering Diploma, from the Dept. of Computer Engineering and Informatics of the University of Patras and a Ph.D. in Medical Informatics from the Medical School of the University of Ioannina. He is an Assistant Professor of Data Modeling and Decision Support Systems in the Bioinformatics and Human Electrophysiology Laboratory, Dept. of Informatics, Ionian University, Corfu, Greece.

Dr. Maria Hadjinicolaou is a Professor, Head of the Applied Mathematics Laboratory, School of Science and Technology, Hellenic Open University, and Director of Studies of the Joint Masters Programme Bioinformatics and Neuroinformatics, 18 Parodos Aristotelous Str., 26335, Patras, Greece, (email: hadjinicolaou@eap.gr). Her main research interests include multiscale, mathematical modeling in biosciences (flow of biological fluids, tumor growth), material sciences (2D materials, graphene), scattering, and also distance learning, distance teaching mathematics, and STEAM.

Dr. Panagiotis Vlamos holds a BSc degree from the Dept. of Mathematics from the National and Kapodistrian University of Athens, and a Ph.D. from the National Technical University of Athens. His research interests include Bioinformatics, Mathematical Modeling in neurodegenerative diseases, and neuroeducation. He is the Chairman of the Board of the Ionian University Research Center, Professor of Bioinformatics in the Bioinformatics and Human Electrophysiology Laboratory, Dept. of Informatics at Ionian University, Corfu, Greece.

Dr. Chrystalla Mouza is Dean and Gutgsell Professor of Education in the College of Education at the University of Illinois Urbana-Champaign (cmouza@illinois.edu). Previously, she was a Distinguished Professor of Teacher Education, specializing in educational technology, and director of the School of Education at the University of Delaware. She earned an Ed.D., M.Ed, and M.A. in Instructional Technology and Media from Teachers College, Columbia University, and completed postdoctoral work at the Educational Testing Service (ETS). She has expertise in learning sciences and teacher learning, applications of technology in K-12 classrooms, teaching and learning outcomes in mobile computing environments and computer science education.

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