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Investigation of Engineering Students' Attitude towards Virtual Labs during the COVID-19 Distance Education

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***Abstract*—This study aims to assess engineering students' experience with virtual labs (VLs) during the COVID-19 distant education. It is based on a questionnaire that was prepared and distributed to students from two Bulgarian universities. The data is used to assess the efficiency of the different instructional delivery methods, the impact of VLs on the respondents' motivation, as well as their vision regarding the future of VLs in the post-COVID educational system. The obtained results indicate that students in different engineering areas have a different attitude towards VLs and even though their motivation is influenced positively, the majority expects face-to-face labs to be dominating over virtual ones.**

***Index Terms*—Distance education, engineering education, motivation, virtual labs**

I. INTRODUCTION

Since the beginning of 2020, the developing COVID-19 situation has led Bulgaria into a lockdown, which influenced all spheres of society. Education was one of the sectors which experienced a partial or full closure. Similar was the situation worldwide, impacting over 91% of the world's student population [1]. In this situation, the face-to-face lessons had to be replaced by distance education literally for one night without preliminary preparation [2], [3]. This was especially challenging for primary and secondary schools that never considered distance learning as an alternative to classic education. In this degree, as a result, did not have the appropriate software, hardware, or staff experience [4]. Since then, many universities remained fully online for more than a year without a single face-to-face lesson. The training was asynchronously or synchronously with or without feedback requirement for completed tests [5]. In many cases, various associations of teachers and students at national, state, and university levels have half-heartedly and hesitantly supported online learning with some curiosity. They tried out new technologies despite the lack of willingness, orientation, and government incentives for the stakeholders to use online learning [4], [6].

Common feedback from distance education was that students were harmed by the low quality of education following the lack of contacts and motivation, stress, limited feedback by the teachers, lack of pedagogical experience [7], [8]. Daniel has found that the loss of skills leads to lower productivity of GDP by 1.5%, and the recovery of the economic situation after the crisis requires students with practical skills [2]. Furthermore, the study showed that students go to universities in order to meet other people and experts, to experience the social life on the campus, to collaborate with researchers and others.

According to Almaiah *et al*., there are four types of challenges towards the acceptance of e-learning: technological, individual, cultural, and course challenges [9]. Due to this, only 15% of the e-learning projects are successful, while 40% are partially failures and 45% are total failures. The implementation of distance education in higher education varied significantly depending on the sphere of education. Programs that rely heavily on practical training, such as agriculture, health, engineering, construction, etc. straggled the most to adjust their classes to remote training. These practical training commonly go hand-to-hand with lectures and tutorials and their combination ensures the necessary educational quality. And even though in some situations the practical training could be simulated remotely, the learning experience is limited [10]. In laboratories engineering, students learn to connect circuits, start electrical equipment, perform electrical measurements, estimate the errors, and tune up the equipment. After the experimental work, they commonly have to prepare a report, which provides a different experience and prepares them for design work, reading of technical documentation, etc.

The integration of information and communication technologies in education such as simulations, virtual and remote laboratories, animations and videos, visualization with real practical work, is considered a promising approach for increasing the efficiency of e-learning [11]. They provide students and their trainers with

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opportunities for remote collaboration and a better understanding of the material, especially when it comes to abstract concepts. Out of them, virtual labs (VL) have a more important role and are gaining popularity. VL environments allow students to investigate different scenarios, perform remote sensor and video measurements, analyze data through online statistical programs, etc. [12]. Furthermore, they help students to better understand the experiments by observing them before their real lab implementation in an appropriate time [13]. Another important advantage is that such technologies are often cheaper than having the actual equipment [14]. According to Kapilan *et al*., in real environments the students gain teamwork skills, however, their attention and deep thinking are lowered because of distractions by the other students or by old equipment [15]. On the other hand, results obtained in Radhamani *et al*. showed that during the COVID crisis the virtual lab users were being less instructor dependent and many of the students accessed the resources without the presence of an instructor [16].

Different studies have also reported the negative aspects of online education and the application of VL. Some of the pedagogical disadvantages of using VL include discouraging students from learning physical instruments and real devices, discouraging collaboration among students, the inability to obtain direct feedback from teachers, increased risk of plagiarism, and lack of practical skills gaining [7], [17]. Southgate *et al*. reported that some of the users of virtual reality (VR) got distracted from the learning process and their actual tasks [18]. Furthermore, simulated labs require students to understand the instructions prior to the experiments, as well as basic computer knowledge [19]. When it comes to VR, physical discomfort can also be added. Clarke *et al*. reported that some users are feeling dizzy after working with virtual reality environments [20] and according to Settgast *et al*. cybersickness can lead to disorientation, discomfort, nausea, and concentration difficulty, which impacts the learning experience [21]. Other studies showed that VLs do not favor the establishment of online interpersonal student-teacher and student-student relations, which has a negative impact on the motivation and discourages a deeper and broader understanding of the course materials and the high-level cognitive abilities [22], [23]. Furthermore, Internet traffic was significantly increased during the Covid-19 crisis [24].

Efficient Virtual laboratories have been developed in all areas of education, such as electric power and heat engineering [25], mechanical engineers [15], physics [26], civil, geology, mining, and petroleum engineering [27], biology [28], medicine and nurses [29], electrical engineering [30], biotechnology [31] and many others. Considering their pros and cons, previous studies have identified various scenarios, where VLs could be successfully applied [4], [25], [26], [32], [33]: lack of the necessary hardware equipment; lack of space; necessity to perform dangerous experiments; absence of teachers or inaccessibility of the campus for reasons such as COVID-19; reduction of chemical waste; possibility to repeat the experiment; etc.

Even though there is enough evidence that the application of VLs could be beneficial, more research is necessary in order to improve the quality of its application. Different studies have investigated the quality of education with online environments and virtual labs. They were based on two main approaches:

- Application of questionnaires to assess students' and tutors' opinion [4], [9], [15], [29], [33]-[36];
- Division of the students in groups and comparison of the study results [37], [38].

Tarhini *et al*. presented a survey result from the application of the Blackboard environment in Lebanon [36]. It investigated the relationship between perceived ease of use, perceived usefulness, subjective norm, perceived quality of work-life, behavior intention, and usage behavior. The results showed that the first four are in direct relationship with the behavioral intention and that behavior intention is in direct relationship with the usage behavior. Babinčáková and Bernard investigated the students’ satisfaction with online chemistry learning [4]. The teachers who participated were well equipped and trained in using various ICT tools. When the students were asked if they enjoyed the online chemistry classes, 20 out of 78 answered “No”. Furthermore, 33% of the students complained they have problems with the understanding of the material during online classes. Students also missed direct contact with the teacher and the blackboard (many students believe teachers can explain things better on the blackboard).

AÅŸıksoy and Islek performed a survey among students regarding the application of virtual labs in the Physics course, mainly related to circuits, electric fields, magnetic fields, etc. [39]. The Circuit lab software was used as the training environment. Students listed their positive and negative views on them. Among the positive were listed the opportunity to reconduct experiments, to design new experiments, the satisfaction when working on a personal computer, the opportunity to conduct experiments individually, having fun, etc. Among the negative aspects were listed not being in a physical environment and also some students were having difficulties using the lab. Reference [15] investigated the application of virtual labs for mechanical engineering and fluid mechanics education in India. Feedback was taken from the students and analyzed. The results showed that 96% of the students were happy with the VL experiments and 80% stated that VL shows the limitations of conventional labs. However, it should be mentioned that in courses such as fluid mechanics it is hard to observe some concepts in a real scenario, while virtual labs have no such limitations. The study also investigated the students’ opinions regarding the ease of implementation of VL, the substitution of real labs with VL, and the integration of VL in the course curriculum, which was generally positive. El Kharki *et al*. presented the results about the implementation of Physics education using a low-cost virtual lab and Moodle in Morocco for Bachelor’s degree students [35]. After the training, a survey was used to assess the student’s opinions. The results showed that 53% of the respondents were very satisfied and 36% were satisfied. The study also investigated 15 questions, regarding the students' motivation, ease of access, expectations, benefits, etc.

Wong *et al*. investigated the effects of a virtual lab and of a microcomputer-based lab via a questionnaire [40]. The results showed that most students found both approaches useful and easy to use. Furthermore, they were positive in their attitude and willingness to use them. Another study has investigated the effectiveness of virtual experiments on the students' achievements and practical skills [33]. During the education were used video materials, excel sheets, and simulations were. A control and an experimental group were used in order to assess the effect and their results were assessed with a test. The results from the analysis showed that there is no statistical difference in the obtained results, i.e. according to the study virtual instruments are as good as face-to-face traditional instructions. Another interesting result is that 60% of the students were initially stressed during their first virtual experiment while the level of stress and anxiety decreased significantly during the 2nd and 3rd experiments as the students became familiar with the teaching methods. Radhamani *et al*. investigated the role of VL as massive open online courses [16]. The study compared results of 2019 pre-COVID students and of the 2020 students that used remote learning. It also used survey-obtained data to assess the 2020 students' opinions. The results showed that 95% of the students agree virtual labs could be used in the absence of an instructor. Even though 79% of the students answered that "virtual labs helped them in learning practical aspects of equipment laboratory, experience, and analysis of results", 81% of them were quite convinced that VL cannot replace real labs. They also stated that the application of VL requires knowledge of computer usage. 24% of the students suggested that VL should be used as a pre-lab learning material and 36% as self-learning material.

Reference [27] reported the results about six laboratories for the degrees of civil, mining, geology, and petroleum engineering that were virtualized using 3D models. Students' and trainers' opinions about the advantages and disadvantages of the VL were obtained using questionnaires. More than 63% of the students agreed that VL are easy to use and 52% stated that they are useful for learning. The lecturers were more in favor of the VL as 77% agreed with the above two statements.

During 2020 and 2021 many students in Bulgaria dropped their higher education because they were not satisfied with it. According to [41] this behavior is expected when the students experience difficulties with learning/understanding and there is a lack of consultations with the teacher. Furthermore, according to [42] there is a medium correlation between the rate of understanding and the rate of implementation of VL, which indicates it is very important for students to understand their tasks and assignments. Other factors that lead to student dropout include internet connectivity issues, lack of appropriate VLs, lack of computer or laptop, lack of appropriate internet skills, and awareness about their responsibilities in online education [15]. Other important aspects are the lack of online teaching skills, appropriate materials applicable in distant education, and appropriate support from the technical teams, as well as traffic overload [3].

This study aims to investigate engineering students' opinions about distance education and more precisely the application of virtual labs during the COVID-19 crisis. It is important to acknowledge the efficiency of different instructional delivery methods for the successful implementation of VLs, as well as their influence on motivation and ease of implementation. This study also investigates students' vision about the future balance between virtual and traditional labs in post-COVID engineering education.

II. MATERIALS AND METHODS

A. *The Teaching Methodology*

During the winter semester of 2020/2021, the students in the Bulgarian universities were studying mostly remotely. This study is focused on the engineering students' experience in the University of Ruse Angel Kanchev (RUAK) and the University of Mining and Geology "St. Ivan Rilski" (UMG). In RUAK the semester began face-to-face for the full-time students and after 5 weeks was switched online while for the part-time students it was entirely online. In UMG the full-time students also studied 8 weeks face-to-face, and thereafter continued in distant form, while the part-time students studied entirely online.

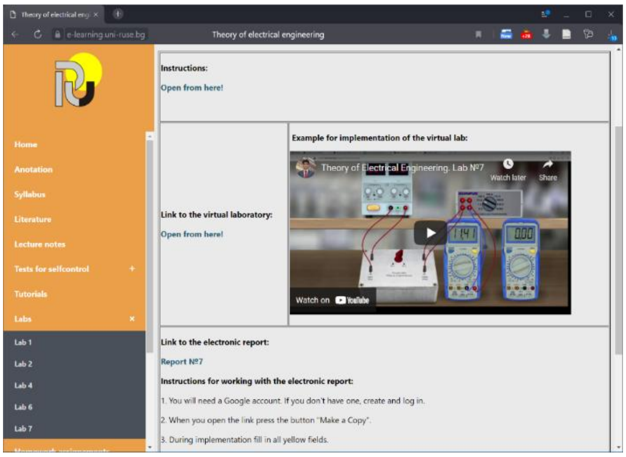
The study covers results obtained subsequently from the courses "Electrical engineering" (RUAK) for Machine and Transport engineering students, "Theory of electrical engineering" (RUAK, UMG) for Computer engineering and Electrical engineering students, and "Electrical engineering and electronics" (UMG) for Mining and Mechanical engineering students. All of the above courses strongly rely on laboratory experiments and for the duration of online education, they were implemented using the Engine for Virtual Electrical Engineering Equipment - EVEEE [43]. EVEEE is a web-based 2D environment, which represents a 3D virtual reality, a screenshot of which is shown in Fig. 1.

Fig. 1. Screenshot from the EVEEE environment, presenting a VL for investigation of a laboratory transformer

From a tutor's point of view, it allows easy creation of virtual labs using a number of existing virtual equipment. Furthermore, students are able to connect their circuit in a realistic environment using virtual cables, plug/unplug elements on a breadboard, set up the equipment, etc., which means that all common parts of a classical laboratory exercise are included. The labs which were implemented by the students in the different courses cover the following topics:

- Basic laws in electric circuits;
- Circuits in sinusoidal steady-state;
- Measurement of electrical current and electrical voltage in DC and AC circuits;
- Investigation of a real transformer (Fig. 1);
- Investigation of the U-I characteristic of a semiconductor diode;
- Frequency response in series and parallel RLC circuits;
- Obtaining the parameters of two-port networks;
- Measurement of active resistances with AV and VA circuit;
- Investigation of Thevenin's theorem;
- Measurement of the power factor in a single-phase circuit.

Instructions for the implementation of the labs were provided asynchronously and synchronously. For each virtual lab were developed written instructions in PDF format and for some of the labs were also prepared pre-recorded video instructions. In RUAK, all available info and links were delivered to the students using the university's e-learning platform (Fig. 2). In UMG, the students received links with the instructions and a pre-recorded video instruction was used for only one of the exercises.



Instructions:

Open from here!

Link to the virtual laboratory:

Open from here!

Example for implementation of the virtual lab:

Link to the electronic report:

Report №7

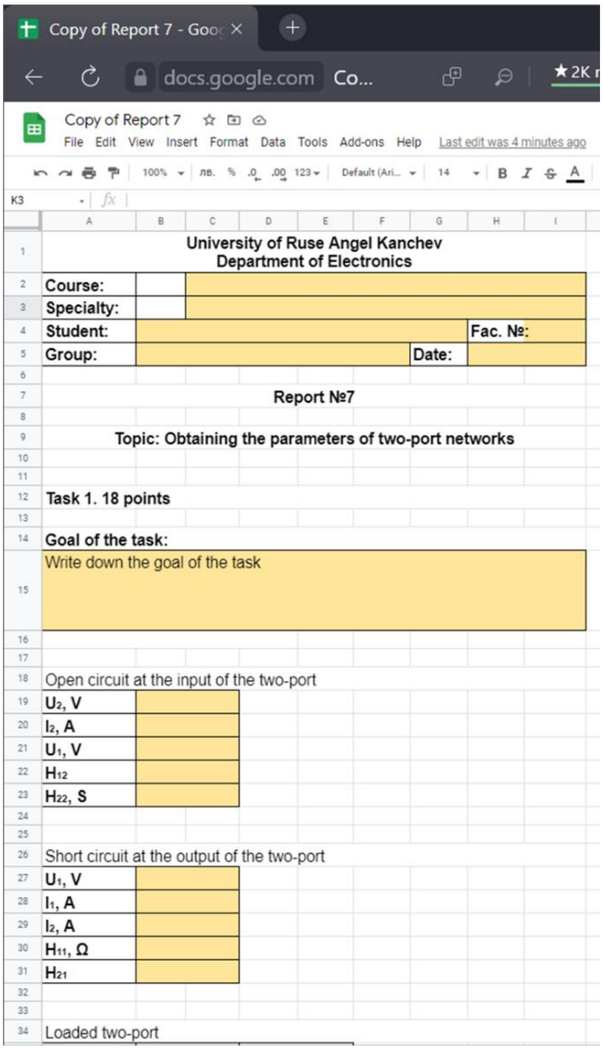
Instructions for working with the electronic report:

1. You will need a Google account. If you don't have one, create and log in.
2. When you open the link press the button "Make a Copy".
3. During implementation fill in all yellow fields.

Fig. 2. A screenshot from the RUAK's e-learning platform that contains instructions for implementing a virtual lab

The synchronous delivery of the instructions was implemented using video conference meetings between the tutor and the students according to the class schedule. Commonly, one of the students was sharing their screen and was implementing the VL under the guidance of the tutor. The remaining students were implementing their lab simultaneously and were asking questions when necessary. Considering a VL normally includes several tasks, for each one a different student shared their screen. Some of the students used mobile devices to implement the exercises and therefore experienced some inconvenience when connecting the circuits.

Traditionally, after performing a lab, students have to prepare a report, which is then provided to the tutor for assessment. This educational approach was also maintained during distance education by preparing an electronic report in Google Sheets for each VL that the students have to fill in (Fig. 3). It includes information about the student, description of the tasks, experimental data, data analysis, charts, and conclusions. Considering not all students have enough experience and computer skills to create their own charts, they were pre-created in the electronic report to automatically draw upon filling in the corresponding tables.



University of Ruse Angel Kanchev
Department of Electronics

Course:
Specialty:
Student: **Fac. №:**
Group: **Date:**

Report №7

Topic: Obtaining the parameters of two-port networks

Task 1. 18 points

Goal of the task:

Write down the goal of the task

Open circuit at the input of the two-port

U_2, V
I_2, A
U_1, V
H_{12}
H_{22}, S

Short circuit at the output of the two-port

U_1, V
I_1, A
I_2, A
H_{11}, Ω
H_{21}

Loaded two-port

Fig. 3. A template for a lab report, pre-created in Google Sheets

It should be noted that many of the students used virtual labs not only in the mentioned courses. Therefore, their opinion is probably influenced by their experience with other environments and courses.

B. The Questionnaire

In order to increase the quality of training and to obtain feedback from the students, a questionnaire was prepared, which includes several sections. The first section was aimed at obtaining the profile of the students (Table I). It collects information about the university, engineering area, years of study, and type of study (part- or full-time).

Table I: Questions Aimed at Obtaining the Profile of the Students

№	Question	Answers
1	In which university do you study?	Open answer
2	In what engineering area do you study?	Machine engineering Electrical engineering Computer engineering Transport engineering Mining engineering
3	What is your year of study?	1st; 2nd; 3rd; 4th
4	What is your form of study?	Full-time student Part-time student

The next part of the questionnaire was aimed at obtaining information about the instruction delivery methods students experienced during their distance education as well as their efficiency. Therefore, several questions were asked regarding the usage level of intensity and the efficiency of video conferencing, virtual labs, recorded video materials, text materials, and e-learning websites (Table II). In this case, the VLs are accepted as a teaching channel, because they replace the real laboratory exercises, which are a standard part of the main curriculum together with the accompanying specifics of their implementation.

Table II: Group of Questions aimed at Assessing the Intensity of Application of Different Distant Education Approaches and Their Efficiency

№	Question	Answers
R1	Rate the intensity of the application of video conferencing (Zoom, Skype, BBB, etc.)	1 (Rarely) 2 (Sometimes) 3 (Average) 4 (Often) 5 (Constantly)
R2	Rate the intensity of the application of virtual labs	
R3	Rate the intensity of application of recorded video materials	
R4	Rate the intensity of the application of text materials (PDFs, doc files, etc.)	
R5	Rate the intensity of the application of e-learning websites	
R6	Rate the effectiveness of video conferencing for providing distance education	-3 (Ineffective) -2 -1 0 (Average) +1 +2 +3 (Highly effective)
R7	Rate the effectiveness of virtual labs for providing distance education	
R8	Rate the effectiveness of recorded video materials for providing distance education	
R9	Rate the effectiveness of text materials for providing distance education	
R10	Rate the effectiveness of e-learning websites for providing distance education	

The next group of questions was targeted specifically at the virtual labs. The students were asked what delivery methods were used to provide instructions for the implementation of VL. Thereafter, they were asked to assess the efficiency of each method (Table III).

The final group begins with three “To what extent is this statement true” questions aimed at obtaining students’ ease of use and interest in working with virtual environments. Then it is followed by three additional questions aimed at investigating the influence of virtual labs on their motivation, as well as their opinion regarding the future perspectives for the application of virtual labs and real labs (Table IV).

Table III: Group of Questions Regarding the Delivery Methods used for Providing Virtual Labs Instructions and Their Efficiency

№	Question	Answers
V1	Did your tutor use videoconferences to deliver instructions for the virtual labs?	Yes/No
V2	Did your tutor use recorded video materials to deliver instructions for the virtual labs?	Yes/No
V3	Did your tutor use text materials to deliver instructions for the virtual labs?	Yes/No
V4	Did your tutor use E-learning websites to deliver instructions for the virtual labs?	Yes/No
V5	How effective was video conferencing for providing virtual labs instructions?	-3 (Ineffective) -2 -1 0 (Average) +1 +2 +3 (Highly effective)
V6	How effective were recorded video materials for providing virtual labs instructions?	
V7	How effective were text materials for providing virtual labs instructions?	
V8	How effective were e-learning websites for providing virtual labs instructions?	

Table IV: The Third Group of Questions, Investigating the Ease of use, the Motivation, and the Future Perspectives for Virtual Labs

№	Question	Answers
Q1	To what extent is this statement true: “It was easy for me to implement the virtual laboratory exercises”?	From -3 (absolutely wrong) To +3 (absolutely correct)
Q2	To what extent is this statement true: “It was easy for me to work with the virtual environment and to use the virtual equipment”?	
Q3	To what extent is this statement true: “It was interesting (entertaining) for me to implement the virtual labs”?	
Q4	In what way was your motivation influenced by the application of virtual labs?	From -3 (very demotivating) To +3 (very motivating)
Q5	In your opinion, could virtual labs become a substitution for real labs?	From -3 (Impossible to substitute) To +3 (Complete substitution is possible)
Q6	In your opinion, what should be the balance between virtual and real labs when the COVID-19 crisis ends?	From -3 (Only real labs) To +3 (Only virtual labs)

C. Data Filtering

Data filtering was performed when assessing the results from the group of questions regarding the virtual labs (V1-V9). When analyzing the results for questions V6, V7, V8 and V9 were counted only those records which had a “Yes” for V2, V3, V4, and V5, respectively. For example, when analyzing the students’ opinion regarding the effectiveness of video conferencing for providing virtual labs instructions were counted only students who answered that their tutors did use video conferencing to provide virtual lab instructions. This filtering guarantees that the results represent the opinion only of students who had personal experience with the corresponding method, thus minimizing the possible errors from recognizing somebody else’s opinion.

D. Data Analysis

Previous studies have shown that there might be significant differences in the students’ opinion, depending on their area of expertise [44]. Therefore, five categories are defined:

- Machine engineering;

- Electrical engineering;
- Computer engineering;
- Transport engineering;
- Mining engineering.

Thereafter, the data is analyzed in two directions:

- Investigation of the survey results for each statement per category;
- Investigation of the correlation between the motivation of the students to use virtual labs and their opinion regarding replacement of real labs with virtual labs, per category.

For the first task, questions Q1 to Q6 are analyzed per category in order to assess the importance of this factor when dealing with virtual laboratories. This is achieved by creating a matrix from the answers to each question:

$$A_{m\times n}=\begin{bmatrix} A_{1(1)} & A_{1(2)} & \cdots & A_{1(n)} \\ A_{2(1)} & A_{2(2)} & \cdots & A_{2(n)} \\ \vdots & \vdots & \vdots & \vdots \\ A_{m(1)} & A_{m(2)} & \cdots & A_{m(n)} \end{bmatrix} \tag{1}$$

where m=1, 2, ···, 7 correspond to the given answers ranging from –3 to 3, n=1, 2, ···, 5 are the engineering areas and $A_{m(n)}$ is the count of the corresponding answers. Thereafter, each column of the matrix is presented graphically for easier understanding.

Furthermore, the average meaning of each column (engineering area) is obtained according to:

$$\text{avg}_n=\frac{\sum_{m=1}^{7}\left(A_{k(m)}i_k\right)}{\sum_{m=1}^{7}\left(A_{k(m)}\right)} \tag{2}$$

where i_k is the numerical meaning of each answer, ranging from –3 to 3. The average meaning avg$_n$ takes values in the range [–3, 3]. A positive value indicates the students of the corresponding engineering area are more or less optimistic about the question while a negative value indicates the opposite. In order to further compare the results among the different engineering areas, the standard deviations at significance level 5% and the 95% confidence intervals are obtained.

The second task is to investigate the correlation between the answers to questions Q4 (In what way was your motivation influenced by the application of virtual labs) and Q5 (In your opinion, could the virtual labs become a substitution for real labs). This would allow us to assess the importance of students' motivation for integrating virtual labs into their classes. This is implemented using Pearson's correlation coefficient. In order to obtain the significance of the estimated correlations, the following hypothesis is tested using the p-value: H0 - The correlation coefficient is not significantly different from zero; Ha - The correlation coefficient is significantly different from zero.

III. RESULTS AND DISCUSSION

The developed questionnaire was prepared as a Google Forms document. It was distributed at the end of the semester to students from the two universities who studied Electrical engineering, Theory of electrical engineering, and Electrical engineering and electronics. The profile of the participants is summarized in Table V. The highest number of students (29%) was studying Transport engineering, followed by Electrical engineering (26%), Computer engineering (17%), Machine engineering (16%), and Mining engineering (11%). Furthermore, the majority of students were in their 2nd year of study (64%), while 1st and 3rd-year students were 17% each. Another important observation is that 64% of the participants were part-time students and the remaining 36% - full-time. It can be mentioned that the URAK students that took part in the survey studied mostly Machine, Computer, and Transport engineering, while the UMG students were mostly involved in Electrical and Mining engineering.

TABLE V: PROFILE OF THE STUDENTS

Category	Profile
University	URAK: 116 UMG: 68
Engineering area	Machine engineering: 30 Electrical engineering: 48 Computer engineering: 32 Transport engineering: 54 Mining engineering: 20
Years of study	First-year: 32 Second-year: 118 Third-year: 32 Fourth-year: 2
Type of formal education	Full-time student: 66 Part-time student: 118

Next, our analysis continued with the rating questions R1-R10. In Fig. 4 is seen that most of the university teachers used a wide variety of instructional delivery methods. The most widely used was "Video conferencing" as 67% of the students stated that it was used constantly. It is followed by "Text materials" (63%), "E-learning websites" (49%), "Recorded video materials" (42%), and "Virtual labs" ("41%). Nevertheless, it can be noticed that a significant percentage of the participants stated that "Recorded video materials" and "Virtual labs" were used "often" - 20% and 23%, respectively.

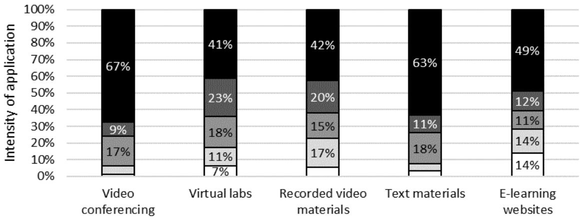


Fig. 4. Answers to questions R1, R2, R3, R4, and R5: "Rate the intensity of application of…"

Students' opinion about the efficiency of each method is summarized in Fig. 5. Text materials and virtual labs were assessed with the highest share of "highly effective" - 46% and 45%, respectively, which coincides with similar results obtained in [40]. Nevertheless, the highest positive score was obtained for "Videoconferencing", for which 79% of the respondent answers were above average, followed by text materials and virtual labs with 75% and recorded video materials with 72%. The teaching method that was assessed as least effective was the application of e-learning websites, which has 63% above average and 26% below average answers.

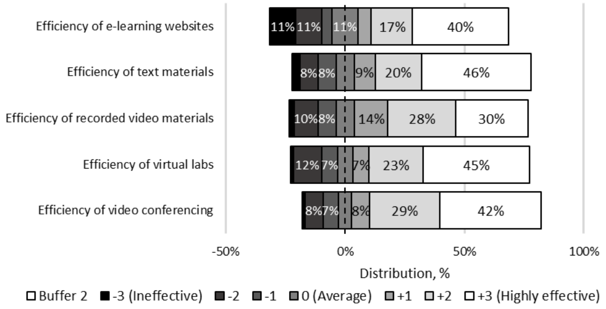


Fig. 5. Answers to questions R6, R7, R8, R9 and R10: “Efficiency of different learning methods for teaching engineering classes”

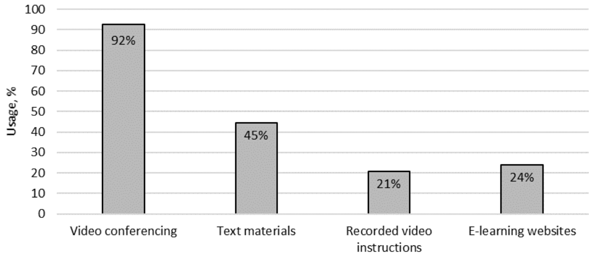


Fig. 6. Percentage of “Yes” answers to questions V1, V2, V3 and V4

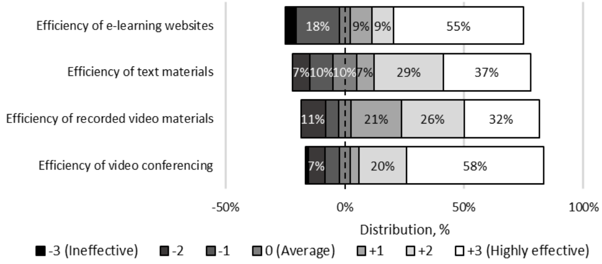


Fig. 7. Answers to questions V5, V6, V7, and V8: Efficiency of different learning methods for teaching virtual labs

Next, in Fig. 6 are displayed the percentile results regarding the used teaching methods when delivering virtual lab instructions (questions V1, V2, V3, and V4). It can be seen that the most widely used method was video conferencing with 92%. The other three methods were used considerably less often: text materials (45%), recorded video instructions (21%), and e-learning websites (24%). The total percentage is above 100% because students had access to more than one instruction delivery method.

According to the developed methodology, when assessing the efficiency of each method were filtered out all respondents that haven’t used the particular method. The results for questions V5, V6, V7, and V8 are summarized in Fig. 7.

It can be seen that videoconferencing is dominating at “highly effective” responses with 58%, followed by e-learning websites with 55%. On average, 81% of the respondents were positive about the application of video conferencing, followed by recorded video materials with 79% and text materials/e-learning websites with 73%. E-learning websites had the highest percent of dissatisfaction with an average score of disapproval of 23%. Nevertheless, in general, all methods were accepted by most of the students. The way the information is presented is important for the students to deal with the virtual laboratory, and this graph proves that the efficiency is the highest when getting acquainted with VL via video conferencing and PDF files. The same is the tendency to deal with the equipment in the virtual laboratory, which is not visualized.

Next, the analysis of the results continues with assessing the influence of the engineering area on the student’s opinion for questions Q1-Q6. In Fig. 8 are presented the answers to Q1 regarding the ease of implementation of virtual labs. As it can be expected, the Computer engineering students have the highest percent of “+3 (Absolutely correct)” answers (44%), with Transport engineering closely after them (41%). Electrical engineering students, for which the course “Theory of electrical engineering” is of fundamental importance, had a significantly lower share of “+3 (Absolutely correct)” answers. Nevertheless, their percentage of positive answers (+1, +2, and +3) was the highest (79%), which can be explained by their better knowledge and interest in the topics. It can be seen that Machine engineering and Mining engineering students had the highest percentage of “-3 (Absolutely negative)” responses, 20%, and 10%, respectively. This indicates some of them were either having difficulties with the implementation of the labs or did not have the motivation to study electrical engineering, which is not a major course in their curriculum.

The obtained results generally correspond to those obtained in other studies. For example, in [15] the students were asked a similar question (Is it easy to learn and do the virtual lab experiments?) and 18% of the students strongly agreed, 59% agreed and 23% were neutral. Nevertheless, it is important to note that students in some engineering areas require more effort from the teacher if they are to implement the VLs.

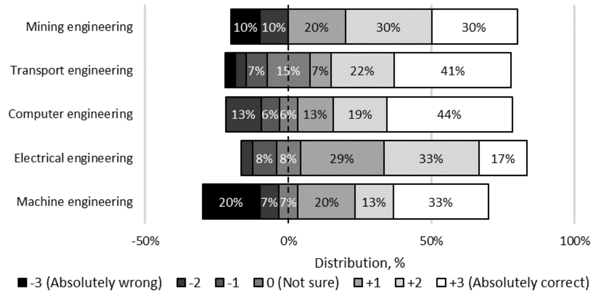


Fig. 8. Answers to questions Q1: “To what extent is this statement true: It was easy for me to implement the virtual laboratory exercises?” per engineering area

In Fig. 9 a similar analysis is performed for Q2 regarding the ease of work with the EVEEE environment and its virtual equipment. Once again, Electrical engineering students had the highest share of positive answers (84%) which is explained by their more advanced knowledge of the topic. The respondents with the highest share of “+3 (Absolutely correct)” answers were the Transport engineering students (44%), followed by the Computer engineering ones (38%). Once again, mostly Machine engineering and Mining engineering students were having difficulties when working with the virtual environment, as 13% and 10% of them, respectively, gave "-3 (Absolutely wrong)" answers.

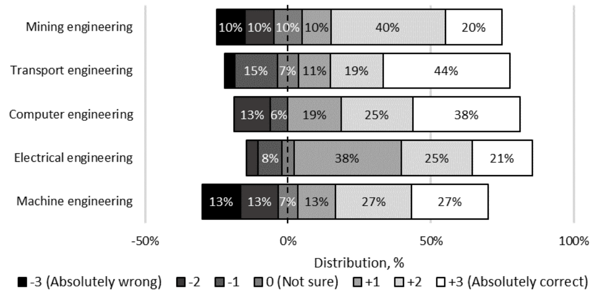


Fig. 9. Answers to questions Q2: "To what extent is this statement true: It was easy for me to work with the virtual environment and to use the virtual equipment?" per engineering area

The results generally correspond with those of previous studies. In [27], 63% of the students studying Civil, Mining, Geology, and Petroleum engineering stated that VLs are easy to use and 17% disagreed.

The answers of Q3 regarding the entertainment that the virtual labs brought to the students are summarized in Fig. 10. Mining engineering students were the most divided in their opinion as 80% absolutely agreed that the application of VLs was entertaining, while the remaining 20% absolutely disagreed. Electrical engineering students were second in a row with 76% positive answers, closely followed by Computer engineering (75%) and Transport engineering (71%) students. Once again Mining engineering and Machine engineering gave a relatively higher percentage of "-3 (Absolutely wrong)" answers - 20% and 13%, respectively.

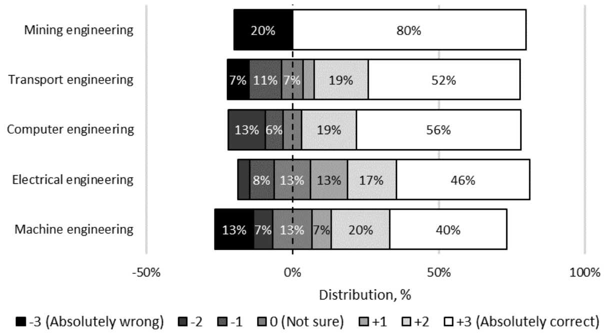


Fig. 10. Answers to questions Q3: "To what extent is this statement true: It was interesting (entertaining) for me to implement the virtual labs?" per engineering area

Q4 deals with the motivation of the students (Fig. 11). It can be seen that virtual labs had the highest positive impact on the motivation of the Mining students and Machine engineering students with 60% and 47% share of the "+3 (Very motivating)" answers, respectively. In general, virtual labs had a positive impact on the motivation of the students from all engineering areas varying from 62% for Transport engineering to 75% for Electrical engineering students. Once again, Machine engineering and Mining engineering had the highest share of skepticism, as 13% and 10% of them, respectively, stated that virtual labs were very demotivating for them. It is also interesting to note that the computer engineering students were the most demotivated by the application of VLs (19% gave negative answers), which contradicts with our expectations, to some extent.

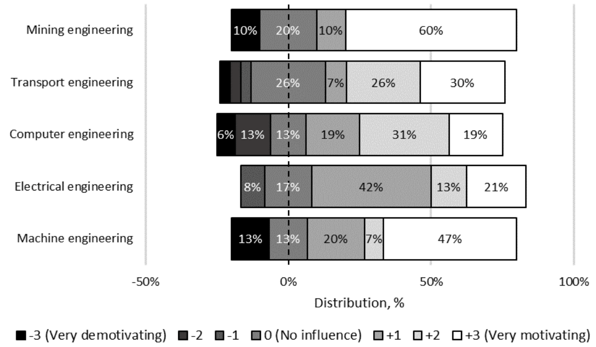


Fig. 11. Answers to the question "Q4. In what way was your motivation influenced by the application of virtual labs?"

If compared with the results from Fig. 10, it can be seen that even though 80% of the Mining engineering students considered virtual labs to be entertaining, only 70% of them considered them to be motivating. Similarly, even though the interest of 20% of the Machine engineering students was negatively influenced by the application of VLs, only 13% considered them to be demotivating. Such observations can be made for the other engineering areas as well. This indicates that a high rate of entertainment does not necessarily mean the same rate of motivation. It could be speculated that this difference is caused by the fact that many students experienced virtual labs for the first time. Furthermore, the division of the Mining engineering students' may be due to the difficulty of the course on one hand and the desire for real face-to-face learning, on the other.

The obtained results generally correspond with those obtained in previous studies. In [35] 77% of the students answered that they were motivated by the use of a virtual environment. On the contrary, in the above study, only 4% of the students were negatively motivated, while the obtained percent in this work is several times higher.

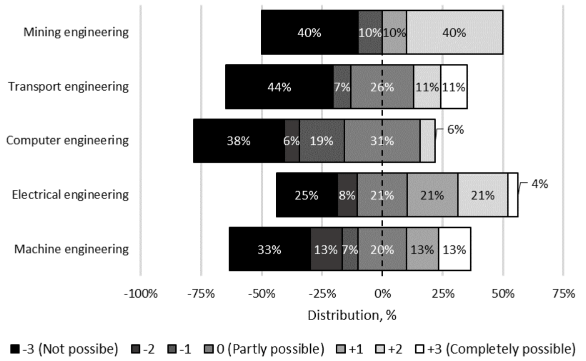


Fig. 12. Answers to the question "Q5. In your opinion, could the virtual labs become a substitution for real labs?"

The next question was aimed at obtaining the students' opinion on substituting real labs with virtual labs (Fig.

12). Here, the division of opinions shows a completely different story. A significant number of students in all engineering areas simply don’t accept such a possibility. The answer “-3 (Not possible)” varies from 25% for electrical engineering students to 44% for transport engineering students and the negative answers are dominating.

On the contrary, the positive answers are mostly +1/+2 and very few students have given a “+3 (Completely possible)” answer. This indicates that students understand the importance of face-to-face frontal practical exercises for their future development as experts. Furthermore, it could be speculated that they do not accept to be deprived of traditional practical exercises without a good reason, such as the COVID-19 crisis. Paradoxically, only 6% of the Computer engineering students consider VLs to be an alternative to real ones, which makes them the most skeptical students.

These results differ significantly from similar results by other studies. For example, in [15] 57% of the mechanical engineering students answered that VL can be an alternative to real labs due to the COVID-19 situation. Yet our results are more positive if compared to [16] where more than 60% of the students strongly disagreed that VLs could substitute real labs and 81% of all were skeptical. Similar results were also obtained in [45], where the substitution options for physics, chemistry, and biology labs were investigated.

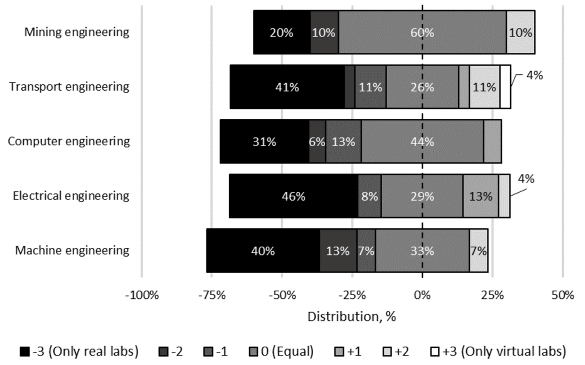


Fig. 13. Answers to the question “Q6. In your opinion, what should be the balance between virtual and real labs when the COVID-19 crisis ends?”

The final question (Q6) of the survey was what should be the balance between virtual and remote labs in the post COVID world. The obtained results (Fig. 13) were even more dramatic as only several students suggested that virtual labs should completely substitute real labs. On average, 38% of the students completely reject the possibility of using virtual labs in the future and insist on training with real labs alone. This result varies among the different engineering areas with the lowest score (20%) in Mining engineering and the highest score (46%) in Electrical engineering. Many students involved in Transport and Machine engineering were also strongly against the use of virtual labs after the COVID crisis – 41% and 40%, respectively.

A significant share of students (35% on average) believes that virtual and remote labs could be equally used in the after COVID education. The highest share is in Mining engineering (60%), followed by Computer engineering (44%), while students involved in other engineering areas are less open to virtual labs. Only 13% of the students believe that virtual labs should dominate real labs, with the highest scores in Transport and Electrical engineering (19% and 17%, respectively).

In general, the obtained results indicate that most of the students would tolerate the application of virtual labs in the after COVID world to some extent, however, they still prefer real labs. These results are especially interesting, considering most students stated virtual labs generally have a positive impact on their motivation. Obviously, the students’ opinion is quite one-sided on the matter for future application of virtual labs. Nevertheless, it could be speculated that this is partly because they had 1 full year of online learning, and they strongly desire to get back to normal education. Here the results differ significantly from other studies. For example, in [15] 71% of the mechanical engineering students suggested that the VLs should be introduced in their curricula in post-COVID learning. It could be speculated that such discrepancy is caused by cultural differences or may be due to the different engineering areas.

A summary of questions Q1-Q6 is presented in Table VI, where the average answers per engineering area are obtained according to equation (2). These results present quantitatively the average students’ opinion. It can be seen that Machine engineering students were having the most problems when implementing the VLs and working with the environment (Q1: 0.73 and Q2: 0.80), while it was easiest for Transport (1.48 and 1.56) and Computer engineering (1.50 and 1.50) students. On the other hand, Mining engineering students were the most entertained and the most motivated by the VLs (Q3: 1.80 and Q4: 1.60).

TABLE VI: STATISTICAL EVALUATION OF THE STUDENTS’ ATTITUDE TOWARDS QUESTIONS Q1-Q6 PER ENGINEERING AREA

Eng. area	Para-meters	Q1	Q2	Q3	Q4	Q5	Q6
Mach. eng.	Average	0.73	0.80	1.13	1.33	-0.80	-1.40
	95%	0.39	0.47	0.79	0.99	-1.12	-1.70
	conf. int.	1.08	1.13	1.48	1.68	-0.48	-1.10
Electr. eng.	Average	1.29	1.33	1.67	1.21	-0.17	-1.25
	95%	1.04	1.08	1.36	0.98	-0.46	-1.54
	conf. int.	1.54	1.59	1.97	1.44	0.12	-0.96
Comp .eng.	Average	1.50	1.50	1.75	0.94	-1.31	-1.13
	95%	1.18	1.18	1.40	0.65	-1.59	-1.38
	conf. int.	1.82	1.82	2.10	1.23	-1.03	-0.87
Trans. eng.	Average	1.48	1.56	1.63	1.26	-0.85	-1.04
	95%	1.17	1.24	1.29	0.97	-1.19	-1.34
	conf. int.	1.79	1.87	1.97	1.54	-0.52	-0.73
Mine. eng.	Average	1.20	1.00	1.80	1.60	-0.40	-0.60
	95%	0.87	0.69	1.37	1.24	-0.74	-0.83
	conf. int.	1.53	1.31	2.23	1.96	-0.06	-0.37
Avg.	Average	1.28	1.30	1.60	1.24	-0.70	-1.12
	95%	1.02	1.05	1.32	1.00	-1.00	-1.37
	conf. int.	1.54	1.55	1.88	1.48	-0.40	-0.87

Computer engineering students were the most skeptical that VLs can substitute real ones (V5: -1.31), yet on average the respondents’ opinion is closer to neutral (-0.70). This shows that most students believe virtual labs could substitute real ones to some extent. The Machine engineering students were the most negative towards working with VLs in the post COVID world (V6: -1.40) because for their successful realization is required training with real machines. Furthermore, the average value for Q6 is quite close to the lowest one (–1.12), which indicates that this opinion is shared among all groups of students. The difference in the answers between Q5 and Q6 once again suggests that the respondents are tired of purely distant education, which most likely influences their opinion. This also indicates that engineering students consider VLs a temporary compromise during the COVID-19 crisis, rather than a real alternative to traditional labs.

Next, the answers to questions Q4 and Q5 were analyzed for a potential correlation using Pearson's correlation coefficient. It takes values from −1 to +1 and its meaning could be explained as follows [46]:

- 0.00-0.19 - very weak correlation;
- 0.20-0.39 – weak correlation;
- 0.40-0.59 – moderate correlation;
- 0.60-0.79 – strong correlation;
- 0.80-1.0 - very strong correlation.

The obtained correlation coefficients are summarized in Table VII. Furthermore, the hypothesis testing shows that they are significantly different from zero, which indicates that they are statistically significant.

TABLE VII. CORRELATION BETWEEN THE STUDENTS' ANSWERS TO QUESTIONS Q4 AND Q5

Engineering area	Pearson's correlation coefficient	t-value	P-value	H0: The correlation coefficient is not statistically different from zero
Mach. eng.	0.38	1.70	2.23E-05	H0 is rejected
Electr.eng.	0.56	1.68	7.62E-07	H0 is rejected
Comp.eng	0.62	1.70	1.44E-09	H0 is rejected
Trans. eng.	0.63	1.67	4.33E-12	H0 is rejected
Mine. eng.	0.81	1.73	3,17E-06	H0 is rejected

It can be seen that the engineering area of the students has a significant impact on the dependency between the students' motivation to use virtual labs and their vision for the VL's potential. For respondents studying machine and electrical engineering, the correlation is weak and moderate, respectively, which indicates that no definite conclusion can be made regarding them. On the other hand, for the remaining categories (computer, transport, and mining engineering) the correlation is positive and either strong or very strong. This indicates that respondents that are more motivated to work with VLs are generally more open to the idea of substituting real labs with virtual ones. And even though many students are still skeptical of the above idea, this might gradually change if they continue to work with virtual labs that have a positive impact on their motivation. This is an important conclusion that opens new options for promoting virtual labs.

IV. CONCLUSION

Since the beginning of the COVID-19 crisis, engineering education is strongly relying on virtual labs. That is why it is critical to investigate and understand students' experiences with them. This study targeted 184 students from five engineering areas involved in electrical engineering courses. The obtained results showed that students' ease of implementation, motivation, and entertainment when dealing with virtual labs, is mostly positive, and varies with their engineering area. Many of them believe that virtual and real labs should go hand-to-hand in the post-COVID world, but there are also many others who find VLs unacceptable in a normal situation.

The results obtained in this study point out some problems that require additional attention. One of them is the necessity to develop and evaluate teaching methodologies aimed at increasing teamwork amongst students when working with virtual labs. This would allow increasing the quality and effectiveness of remote engineering training, thus providing additional experience and satisfaction.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

BE and TH proposed the idea, prepared and conducted the survey. All authors prepared the methodology, participated in the data collection and analysis. BE and TH wrote the paper. All authors had edited and approved the final version.

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