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Virtual Reality Remote Access Laboratory for Teaching Programmable Logic Controller Topics*

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This study is concerned with improving the effectiveness and quality of technical education through the use of virtual reality technology. To do so, we have examined the effects of an application of a Virtual Reality-Supported Remote Access Laboratory (VRRALAB) system we developed using remote access and virtual reality technologies on students' learning experience. The advantage of such a remote access laboratory is that use of equipment that requires experience, such as working under high voltage, can be hazardous to novice users, whereas interactively using a real device from a virtual reality-supported remote access laboratory environment comes with no such risk. We have used an experimental design with 74 associate degree mechatronics program second class students who were divided into the control and experiment groups. They were enrolled on the same Programmable Logic Controller (PLC) course using the applications prepared for VRRALAB design. The experimental group was given a 4-hour training session using the basic subjects of a PLC lesson with the VRRALAB application with a traditional method, whilst the control group was taught only in conventional fashion. Both the control and experiment groups were assessed using the same exam questions. It was found that students who studied with VRRALAB were more successful than those who did not. Satisfaction levels among students using VRRALAB were also found to be high when measured by a questionnaire survey. The results indicate that remote access laboratories using virtual reality are likely to increase the quality of learning and satisfaction levels.

Keywords: virtual reality; augmented reality; remote lab; PLC training; education

1. Introduction

The use of virtual laboratories is contributing to the development of the education and research sectors. Hence, the increasing use of such training methods warrants new designs to be devised [1]. Labs with advanced simulation features along with specialist software can replicate real-life experiences and thus prove beneficial [2]. In contrast, training methods offering only theoretical knowledge are inadequate in vocational and technical education. However, establishing large-scale laboratories for vocational training providers is not easy because of both financial and space implications. Technological developments, the advance of 3-D models which become more realistic day by day, means these models' ability to access details that cannot be obtained in physical laboratories. The interactive operation of real and virtual objects will not only be beneficial in terms of physical space and finance, for this will also bring involve bringing in features that will improve the quality of education. Showing virtual physical equipment facilitates education [3]. Rapid virtual designs and practical applications can bridge different platforms via remote access virtual laboratories [4]. Remote-access laboratories are interactively complementary to traditional laboratories [5]. An online laboratory is able to track and store useful data for evaluating the work of the students [6]. Moreover, online engineering education provides added value, such as image, benefit and trust, while also promoting blended learning [7, 8]. Hence, the virtual laboratory represents a better alternative to building a traditional laboratory for support engineering education courses [9]. The training provided with virtual laboratories offers the possibility of working simultaneously with virtual and real equipment and 24/7 access to a laboratory environment with a remote access feature. Moreover, virtual support software reduces the need for physical space is the virtual interface as the technological infrastructure can be applied to any desired environment. This means possible cost savings.

Virtual and remote access laboratories have been around for more than 20 years, being used at all educational levels. There have been substantial advances in the development of virtual and remote laboratories in education [10]. Remote labs help to improve learning quality in laboratory education [11], being able to perform real physical interactions over the Internet with remote access users [12]. Often, virtual laboratories are used as desktop software or web-based applications [13].

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There is an abundance of studies on virtual reality and its use around the world, with several streams being identifiable in this literature. For instance, Madathil and Greenstein developed a virtual collaborative three-dimensional remote manageable usability testing laboratory to measure application performance and demonstrated that participants were productive in a virtual reality environment [14]. Heradio et al. reviewed the studies on the virtual and remote access laboratories in education from their beginnings up until 2015 to produce a science map and performance analysis with two known bibliometric methods [10]. Wolfartsberger studied the potential of developing and evaluating a virtual reality-based tool for engineering design and concluded that intuitive interaction with virtual reality would accelerate design review [15]. In another study, Heradio et al., conducted a virtual and remote access laboratory development in automatic control training and noted a significant price reduction in most of the equipment required for the establishment of remote access laboratories [13]. In the same vein, Liagkou and colleagues studied the realisation of a virtual reality learning environment for industry 4.0 and found that it relied on virtual reality to reduce design and production costs, maintain product quality, and so on [16]. Grodotzki et al. studied capacity optimisation and costing models with remote and virtual labs for engineering education 4.0 and highlighted the need for virtual reality in the training process [17]. Tawfik and colleagues studied virtual instrument systems in the remote wiring of electronic circuits on breadboards and discussed the feedback from the universities that implemented the application in their curriculum [18]. Fraile-Ardanuy and colleagues developed an integrated virtual remote access laboratory to teach the methods of asynchronous motor operation. They further experimented it with some students, and based on their feedback, developed a user-friendly interface [19]. Marques and colleagues developed a variety of applications to assess the impact of remote access laboratories on course outcomes using virtual reality. When combined with a practical laboratory, they demonstrated that this is a good choice as students can diversify their learning paths, while being able to practice freely and thus, increase their confidence in laboratory skills [20]. Virtual reality studies in the field of engineering in higher education have been increasing over the years. [21]. VR platforms can be seen as having three functions, namely presenting information, teaching practical skills and teaching how to use the knowledge acquired in the face of problems [22]. Previous studies have also shown that virtual and augmented reality support research focused on applied courses and mobile learning, amongst other aspects, in engineering education [23–25].

The features of engineering and technology education make it possible with applied laboratory studies to increase knowledge and skills growth. There is a need to build virtual laboratories by growing the sense of reality in order to address the difficulties of having the requisite physical environments for adaptation to emerging technologies. In reviewing the literature, it was seen that the experimental design used in this study was used on students enrolled on PLC training and that this would be successful. It has been used in simulation-based studies and physically-equipped remote-access studies [26–28]. Virtual labs help students' understanding of the topics of courses [29]. PLC education, is an important module in vocational and technical education, was preferred to investigate the use of VRRALAB in the PLC course. This study's contribution to the literature is based is that it enables the physical and virtual equipment to work together and simultaneously. In Section 2, we present the system architecture, including the software and hardware used in examining the use of VRRALAB on the PLC course. Implementation of PLC based VRRALAB is described in Section 3. In Section 4, the results are provided along with a discussion of these. Conclusions are provided in Section 5 and proposals for future research on this topic are made.

2. Materials and Methods

The formation of a real-time application with virtual reality support consists of the phases of environmental creation and system design, modelling, materials and hardware integration, software integration, and optimisation [30]. This section provides the details of the VRRALAB system used. First, the system architecture and equipment utilised are described, which is followed by an explanation of the hardware used in the system and finally, the implementation of VRRALAB and 3-D application details are provided.

In this study, we have used an experimental design with 74 second year students enrolled in an associate degree programme of mechatronics. All students were recruited from Istanbul Gedik University Vocational School in Turkey during the second semester of 2018–2019 academic year. These participants were divided into the control and experiment groups. They were enrolled on the same Programmable Logic Controller (PLC) course using the applications prepared for VRRALAB design. The experimental group was given a 4-hour training session using the basic subjects of a PLC lesson with the VRRALAB application with a

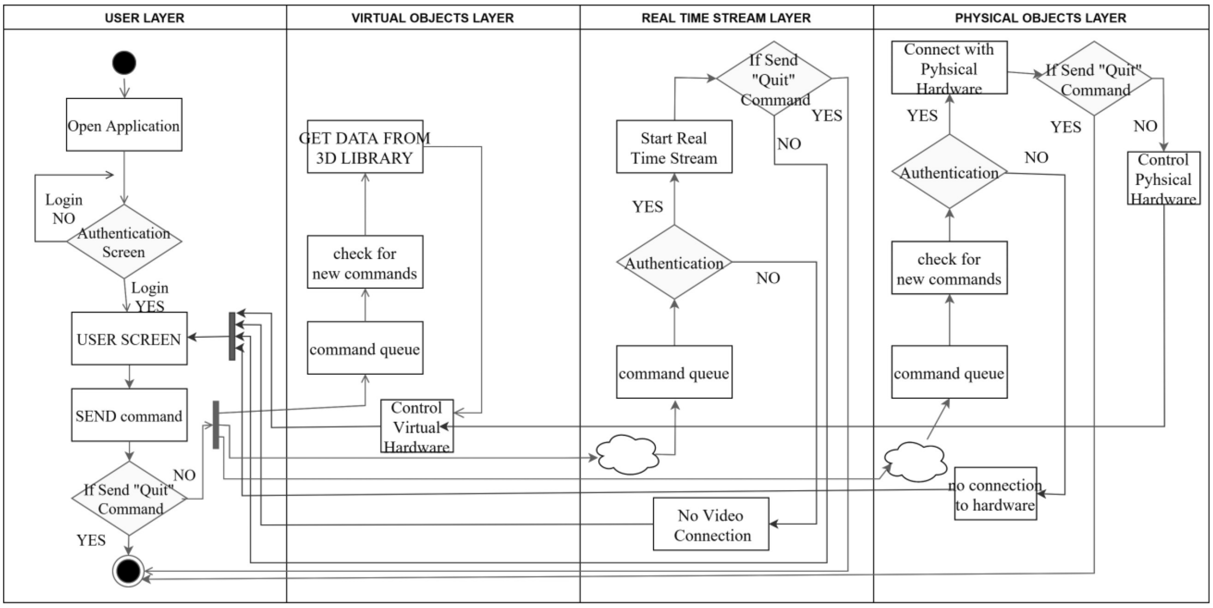

Fig. 1. UML System architecture for the proposed virtual reality supported remote labs.

traditional method, whilst the control group was taught only in conventional fashion. Both the control and experiment groups were assessed using the same exam questions.

2.1 System Architecture

Instant access, real-time control, user-friendly interface design and optimisation are considered as requirements in the system architecture development phase. Fig. 1 presents the Unified Modelling Language (UML) activity diagram, illustrating the architecture of the developed system in a four-layered structure. That is, the system diagram shows the general structure of the VRRALAB environment.

The layers are labelled as: (1) the user layer, (2) the virtual objects layer, (3) the real-time stream layer, and (4) the physical objects layer. The system is designed in such a way that the connections between these layers can be controlled by the user layer. The user layer environment can be designed as an interface screen of a computer, tablet, smartphone etc. In this study, an Android based interface was designed. The hardware in the layer of physical objects accessed with the designed user interface must have an infrastructure that can be controlled by remote access in accordance with the training to be provided. For real-time monitoring of the remote states of physical objects, a real-time stream layer was created using an IP-based camera. The layer that contains a library, where virtual hardware is stored and can be connected to the physical hardware that can be controlled and displayed in the user interface, is called the virtual objects layer. The real-time control of the virtual hardware in this library interacts with the physical hardware through the user interface. Cloud technologies, various programming languages and access technologies are used to facilitate interaction between these layers. Control of the remote access hardware is performed with the Internet of Things (IoT) as well as other hardware and software for operating the system, which is described in the next section.

2.2 Software and Hardware

The four-layered structure of the remote access laboratory with virtual reality support for the selected PLC course for implementing the developed system architecture is shown in Fig. 2. The user layer interface is designed to be Android based. The reason for choosing an Android-based interface is that the smartphone and tablet prices are affordable and for coding, only a computer is needed. The 3D objects in the virtual hardware layer are designed in the Blender program. The interface design was created with the powerful visualisation software Unity3D [31].

The physical hardware of VRRALAB is shown in Fig. 3. For the physical equipment of VRRALAB, PLC, RaspberryPi and relay control board, IP camera and an LED lamp are used. It requires only a cubic space of $50 \times 50 \times 50$cm. MODBUS TCP/IP method was chosen for remote communication with PLC. In order to control the input information of PLC, IoT technology is used. Raspberry Pi (RPI) is a mini-computer using gpio pins to communicate with electronic systems [32] and relay control card integrated into the Raspberry pi 3 model is controlled by means of RESTAPI (Repre-

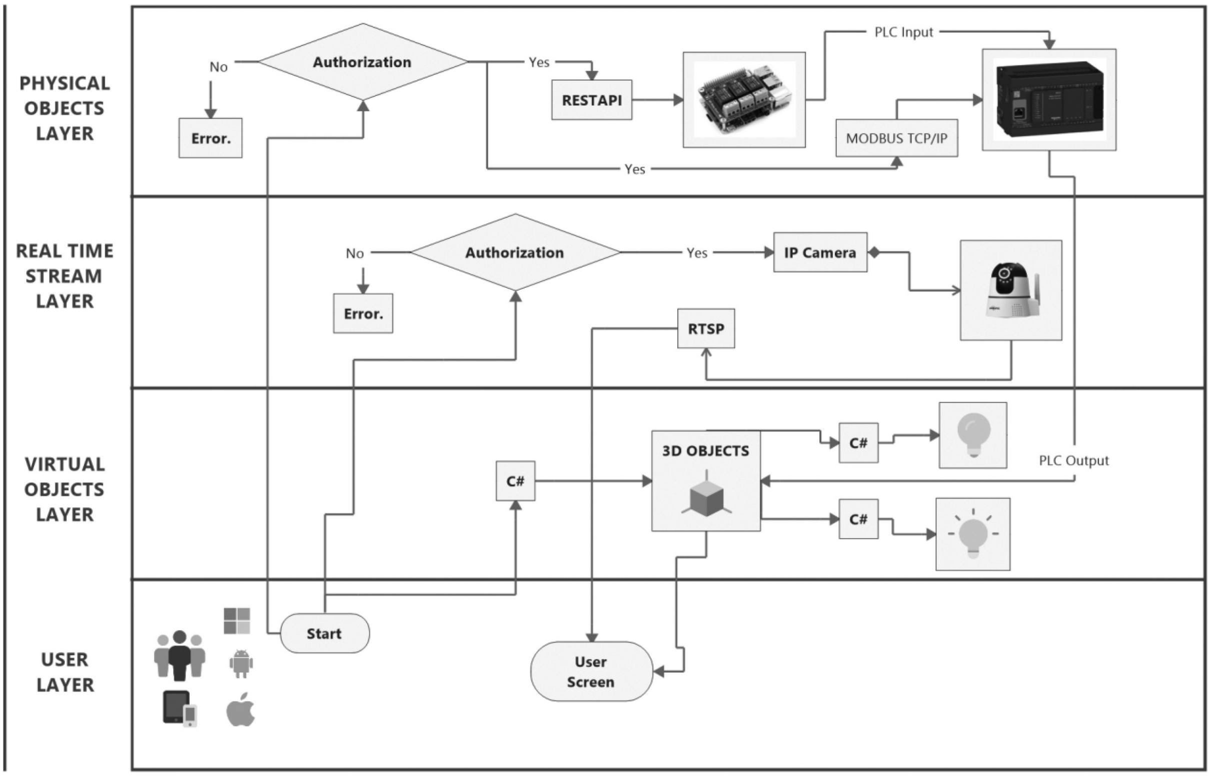

Fig. 2. VRRALAB 4-layered structure for teaching PLC flowchart.

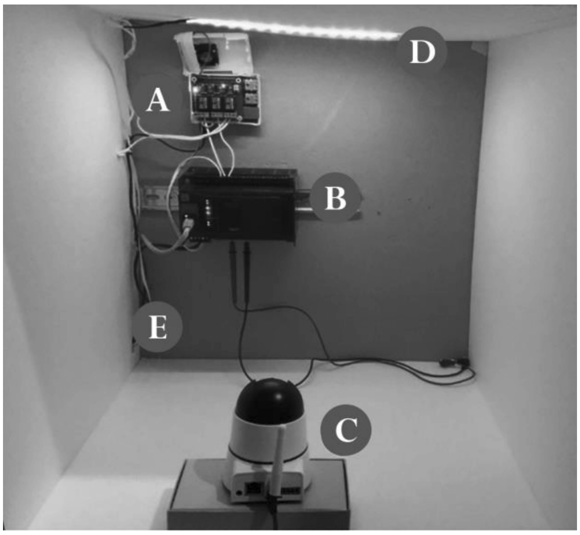

Fig. 3. Remote laboratory equipment for PLC training module. (A) Raspberry Pi 3 & Relay Board, (B) PLC, (C) IP Camera, (D) Light, (E) 24V DC Power Supply.

sentational State Transfer Application Programming Interface) communication protocols.

3. Implementation of PLC based VRRALAB

An outline of the communication between the physical equipment is shown in Fig. 4. The communication with the IP camera used for real-time video transmission was achieved with the RTSP (Real-Time Streaming Protocol) protocol. UNITY3D software was utilised to develop the android-based application for the virtual reality that supported the remote access laboratory. The software uses the C# programming language.

Lecture notes were prepared to be used with the application. These lectures explain the basic level of PLC, the application areas, differences between control circuit, input elements, output elements, models, ladder diagram and basic applications. The QR code provided in the lecture notes allows students to download the application to their Android-based phones or tablets. On the first screen of the downloaded application, the students enrolled on the system see the application screen interface shown in Fig. 5, where a physical PLC transmitted using an IP camera in real-time is shown. PLC inputs are transistor-controlled and as aforementioned, for active-passive control of these inputs, IoT technology is used.

The system is controlled by virtual buttons on the screen, which activates pre-written C# codes. The 3DPLC button opens the virtual 3D model of the physical PLC. As shown in Fig. 6, on the touch screen, users can navigate the 360-degree and zoom in/out 3D model with their fingers. This enables the students in training accessing the necessary detailed information about the virtual and physical hardware.

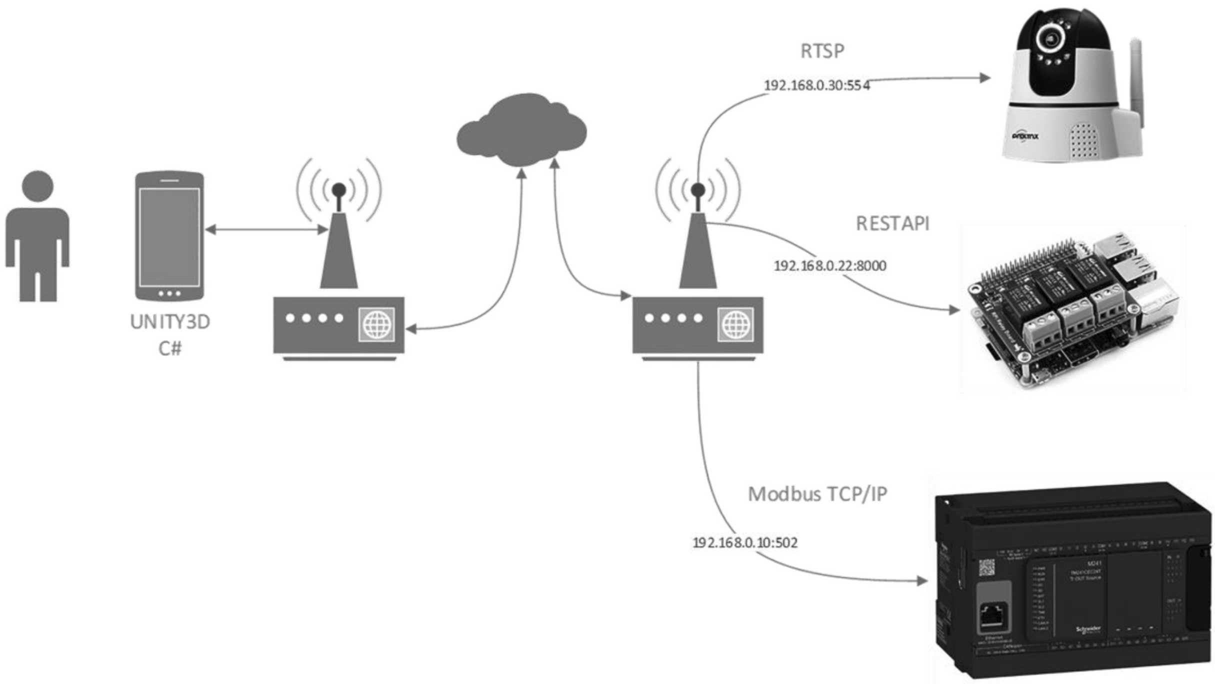

Fig. 4. Virtual reality supported remote access PLC training module communication chart.

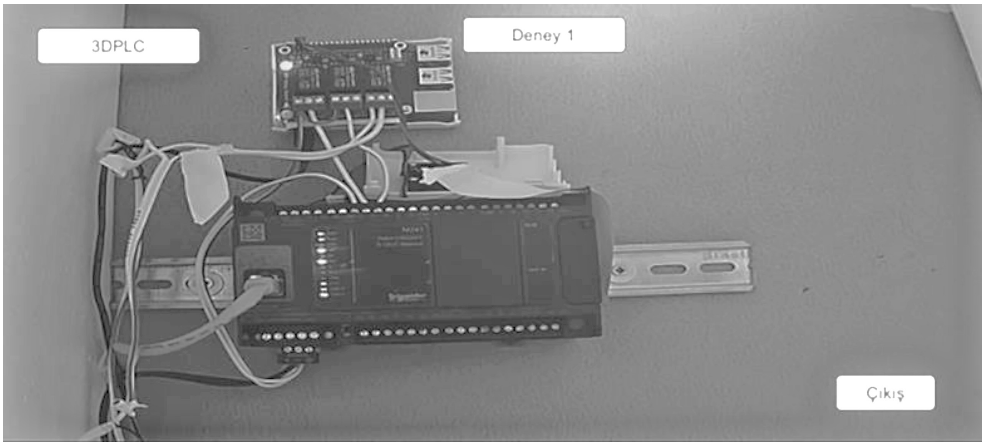

Fig. 5. VRRALAB application user screen screenshot from an Android based smartphone.

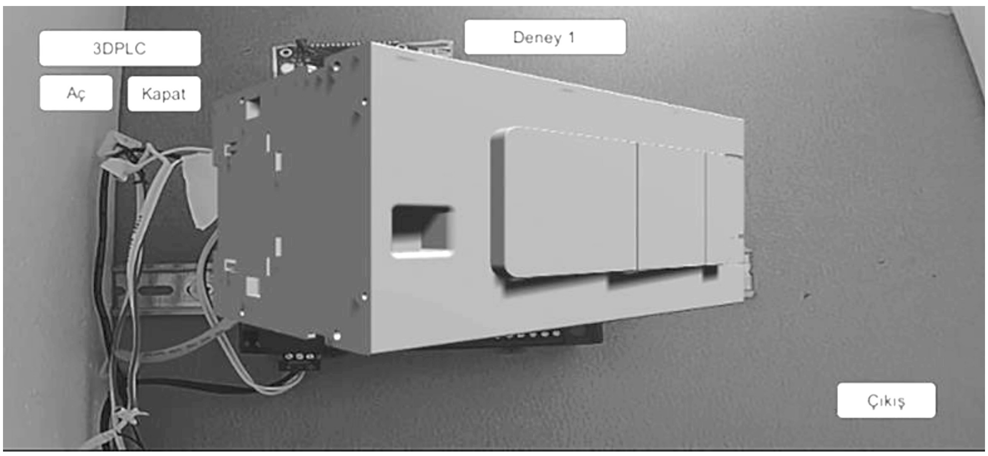

Fig. 6. VRRALAB application 3D PLC model shown on a user screen screenshot.

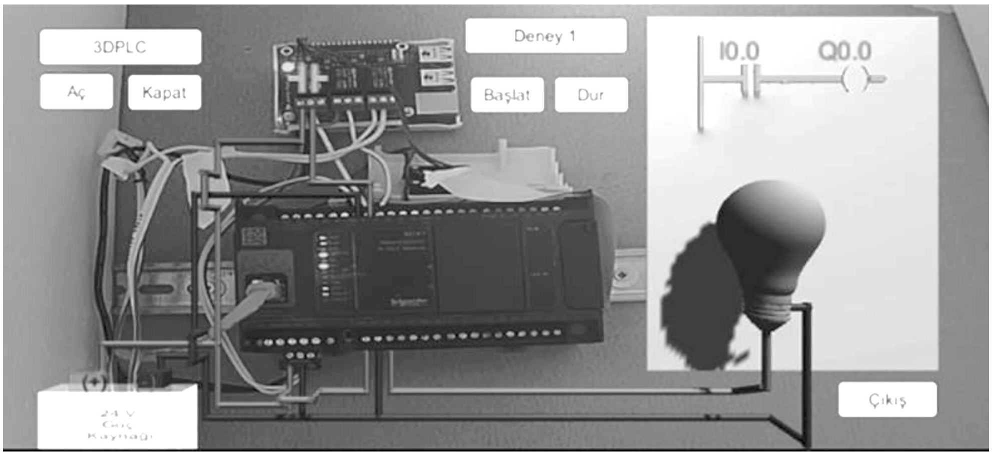

Fig. 7. VRRALAB application virtual "Deney1" button clicked screenshot for the experiment shown on screen.

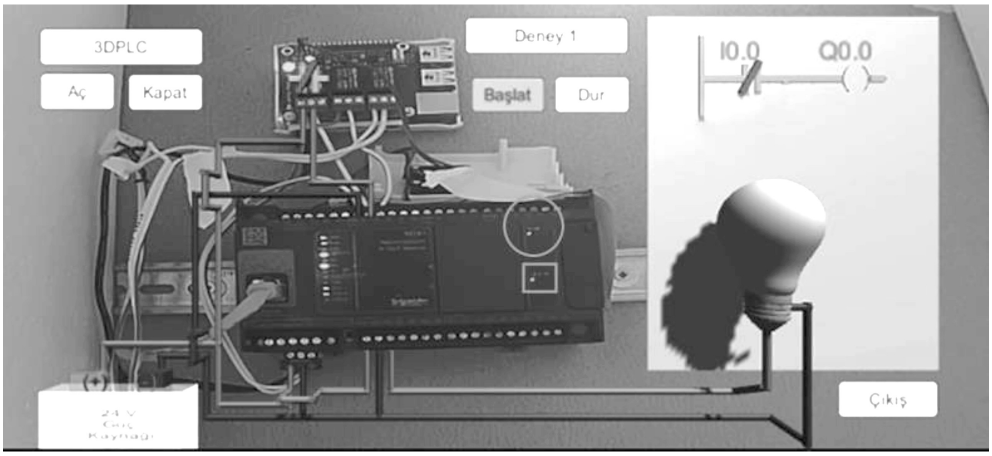

Fig. 8. VRRALAB application virtual "Baslat" (Start) button clicked screenshot for the experiment start mode.

Using the Deney1 button, the experiment created with 3-D virtual objects can be seen in Fig. 7. Here, a 3D lamp, the virtual electrical connections of the lamp with PLC, the virtual power supply and the ladder connection diagram of PLC can be seen. There is a virtual whiteboard on the right side of the screen on which information about the experiment is displayed. The shadows of the virtual objects shown on the screen are also visible.

When the Start (Baslat) button is pressed, the programmed software communicates with the PLC and becomes active, as shown in Fig. 8. When activated, the I0.0 address input information of the PLC is activated by the relay card communicated with the RPI, whilst the Q0.0 output information is activated depending on the ladder diagram scenario loaded in the PLC. This information is shown in the input-output control LEDs of the PLC in the circle and square on the screen shown in Fig. 8. At the same time, when the output information is active, it is seen that the virtual 3D lamp is active. The ladder diagram shows that normally open contact is closed. When the Stop (Dur) button is pressed, the relay connected to the RPI will be in the passive position and the I0.0 input information of the PLC will be in the position. Thus, the output information of the PLC will be passive and the virtual lamp will not be lit. When the Quit (Cikis) button is pressed, all the changes will be restored to the initial position and the application will be closed.

4. Results and Discussions

The virtual reality applications prepared for the VRRALAB design, the success of the course and the evaluation of it are measured by the experimental method. Regarding the experimental design, half (37) the students of undergraduate programmes were allocated to the experimental group and the other 37 were selected for the control group. The developed VRRALAB application was used by the students in the experimental group in the PLC class. The students in the control group were given traditional lectures for which they received only lecture notes. Within a traditional PLC course, a

Table 1. Mean results for success in the exam questions for the control and experiment student groups

No	Experiment Group Mean	Control Group Mean	Mean Difference	Total Mean	Learning Level
Q1	8.9	3.8	5.1	6.4	Conceptual
Q2	5.9	0.5	5.4	3.2	Conceptual
Q3	8.6	3.8	4.9	6.2	Conceptual
Q4	9.7	0.5	9.2	5.1	Conceptual
Q5	10.0	8.4	1.6	9.2	Practice
Q6	10.0	8.4	1.6	9.2	Practice
Q7	9.5	7.6	1.9	8.5	Practice
Q8	8.9	2.2	6.8	5.5	Practice
Q9	6.5	1.1	5.4	3.8	Practice
Q10	0.0	0.0	0.0	0.0	Practice

virtual reality supported laboratory application with remote access was tested on students within the scope of the 4-hour course.

Training content for the Programmable Controllers course: ''control circuit elements (buttons, signal lights, contactors, etc.), PLC ladder diagram creation, bit logic commands and sample applications'' were determined. The training objectives of the Programmable Controllers course were to recognise the programming symbols with PLC input elements and a ladder diagram. The learning outcomes were to ''Recognize the input and output elements and learn to programme the symbols of the elements and the ladder diagram.''

The success of both groups after the class was measured by using the same course exam questions. The exam questions are designed according to two aspects, namely conceptual and practical, to be evaluated across 10 questions. Specifically, as can be seen in Table 1, Questions 1–4 are conceptual, whilst Questions 6–10 are practical. Regarding the level of success for the questions that require learning at the conceptual level, it can be seen that the difference between the achievement averages of the experimental and control groups is 5.1 for Question 1, 5.4 for Question 2, 4.9 for Question 3 and 9.2 for Question 4. Notably, for Question 4, the experimental group was more successful than the control group by the highest difference of 9.2 points, which pertained to ''Write the PLC hardware.'' This indicates that the conceptual education provided by VRRALAB is much more effective than traditional education methods. Practical questions are assessed on three levels: easy, medium and hard. Questions 5, 6 and 7 are easy, Questions 8 and 9 are medium and Question 10 is hard. According to the exam results, it can be seen that the experimental group was more successful in the easy and medium practical questions than the control one. In particular, regarding the 8th and 9th questions, which are diagram drawing questions, the experimental group average was significantly higher than for the control one. (6.8 & 5.4). This implies that medium-level practical training with VRRALAB is

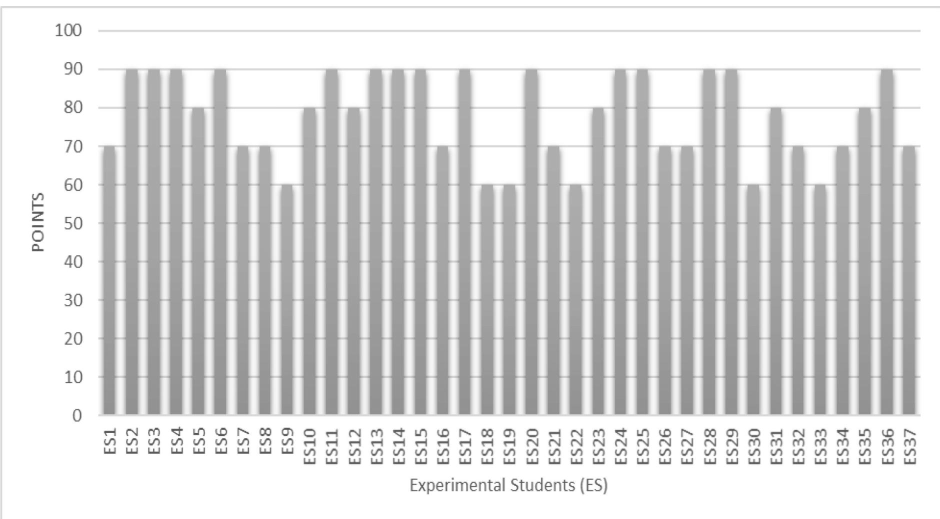

Fig. 9. Experimental group achievement assessment chart.

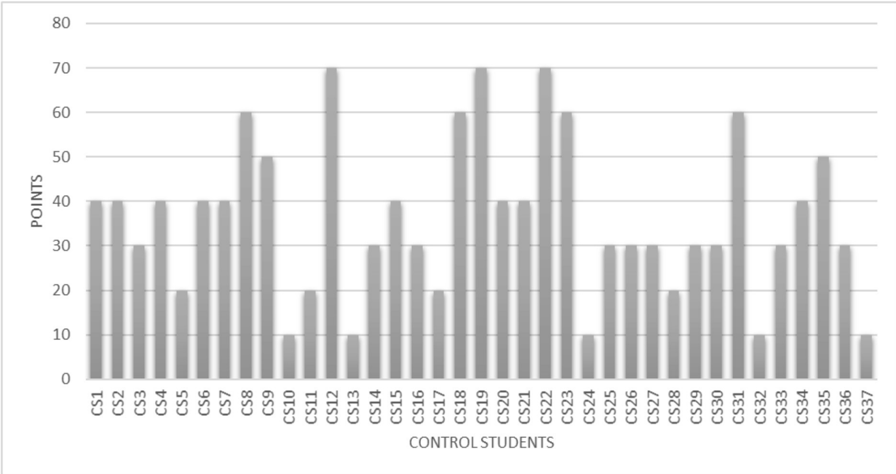

Fig. 10. Control group achievement assessment chart.

better understood than that through traditional methods. Notably, it can be seen that both groups could not answer the 10th question and we intend to investigate why this was the case in follow up research. In sum, according to the results of the exam, it is concluded that the training using VRRALAB delivers greater success in both the conceptual and practical aspects than that conducted according to traditional methods. Success evaluation graphs for each participant are shown in Fig. 9 & Fig.10 for the experimental and control groups.

Success evaluation graphs are shown in Fig. 9 & Fig. 10 for the experimental and control groups.

As can be seen in Fig. 9, 31 out of 37 students in the experimental group had a success of 70 marks or more. This indicates that the success rate of the course is 85% by using the virtual reality supported remote access laboratory application if the achievement assessment score were set to 70 marks. This shows that students' self-learning increases the average success by means of the virtual reality-supported remote access laboratory practice.

As seen in Fig. 10, only three out of 37 students in the control group had a success rate of 70 marks or more. If the successful assessment score is set as 70, this shows that the success of the course is just 8%. Hence, it is concluded that the course achievement of the students using only lecture notes is disappointingly low.

Table 2 shows the average success level of the experimental group was 78.1 out of 100, whilst that for the control group was 36.2 out of 100. These findings suggest that students who use VRRALAB applications are more successful than others (Table 2).

According to the results of the t-test, the achievement level of the experimental group students was higher than for the control group students ($t_{0.05:72}$ = 12.149).

Another measurement tool of the study is the questionnaire form used to measure the effectiveness of the course in terms of student satisfaction with the VRRALAB application. The "Instructional Material Motivation Scale" questionnaire, which assesses the four dimensions' reliability, attention, satisfaction and relevance, has been adapted for virtual reality studies and was measured by the scale developed [33] for the current study.

Before evaluating the survey questions, it is useful to establish the reliability of the research. Cronbach's Alpha test was used to measure the reliability of this research, which is a method for assessing the level of internal consistency and is defined as given below. It takes a value between 0 and 1. It is evaluated as 70–85% good and 85–100% very good in reliability measurement. Cronbach's Alpha value for this research is good at 75.5% (see Table 3).

"Confidence" is the first dimension of the questionnaire used in this study and it is measured with 9 questions designed as a 5-point Likert-type scale. The average score for the participants' confidence was found to be 4 out of 5. This shows that the

Table 2. T-test table for success results of the control and experiment group students

Group	N	Mean	Standard deviation	Sig.	t	Df	Sig. (2-tailed)
Experiment	37	78.1	11.5	0.054	12.149	72	0.000
Control	37	36.2	17.5		12.149	62	0.000

Table 3. Reliability statistics of questionnaire

Reliability Statistics		
Cronbach's Alpha	**Cronbach's Alpha Based on Standardized Items**	**N of Items**
,755	,835	36

course with VRRALAB application was likely to increase confidence among the students enrolled. That is, the participants considered the experience of the VRRALAB application as supportive of their confidence in the related course.

Considering the first 9 questions in which the Confidence dimension is measured in Table 4, the first impressions of the students regarding this course is that it was easy for 75% whereas only about 30% found it difficult to understand the VR application (Q2). After reading the introductory information, 76% understood what they need to know (Q3). However, 35% found it difficult to identify the important information due to clutter (Q4). The vast majority of students (89%) were confident that they can learn the course contents using VR application (Q5). Only 20% found the exercises were too difficult (Q6). Similarly, only 19% expressed that they could not understand the VR in blended learning (Q8). 76% of the students also found a good organization of the content conducive to learn confidently (Q9). As a result, it was clear that 84% of students felt confident that after working on this course for a while, they would be successful in the exam (Q7). When the questions forming the Confidence dimension are evaluated, it can be said that the participants thought that the virtual reality supported remote access laboratory application could be used reliably for this particular course.

"Attention", the second dimension in this study, was measured with 11 questions and the participants gave an average of 4 out of 5 for this dimension. Hence, the participants found the experience of the VRRALAB application was conducive with enhanced attention when undertaking the course.

When the questions between 10–21 in Table 5 are considered, where the attention level is measured, 84% of the participants were interested in the course using VR (Q10), 81% of them found the course noteworthy (Q11, 81%), and 84% of them appreciated the quality of writing (Q12). 68% of the participants felt the lesson was not abstract and remarkable (Q13) and 75% of they the lecture notes were interesting (Q14). 90% of students were happy about the way the information was organized in the pages (Q15) while 43% found repetition distracting (Q17). However, 46% do not appear to be distracting (Q17). 87% of them found the content stimulating curiosity (Q16) and 81% of them were positive about facilitating effect of learning surprising and unexpected things (Q18). Variation in content including illustrations and pictures helped them to stay alert (Q19, 79%) and only 16% found the style boring and irritating clutter on pages (Q20 and Q21). In addition to 60% of the participants do not find the lesson boring and 73% irritating (Q20 and Q21).

Regarding the questions that constitute the attention dimension, it can be said that the participants

Table 4. Questionnaire Confidence dimension questions and experiment group response percentages

	Strongly agree	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**
1. When I first looked at this lesson, I had the impression that it would be easy for me.	32%	43%	22%	3%	0%
2. The VR was more difficult to understand than I would like for it to be.	14%	10%	46%	14%	16%
3. After reading the introductory information, I felt confident that I knew what I was supposed to learn from VR experiences.	46%	30%	22%	0%	2%
4. Many of the pages had so much information that it was hard to pick out and remember the important points.	8%	27%	32%	22%	11%
5. As I worked on this lesson, I was confident that I could learn the content.	54%	35%	8%	3%	0%
6. The exercises in this lesson were too difficult.	4%	16%	32%	24%	24%
7. After working on this lesson for a while, I was confident that I would be able to pass a test on it.	46%	38%	16%	0%	0%
8. I could not understand quite a bit of the VR in blended learning.	5%	14%	41%	16%	24%
9. The good organization of the content helped me be confident that I would learn this VR technology.	54%	22%	24%	0%	0%

Table 5. Questionnaire Attention dimension questions and experiment group answer percentages

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
10. There was something interesting at the beginning of lesson using VR that got my attention.	57%	27%	14%	0%	2%
11. These materials are eye-catching.	59%	22%	14%	3%	2%
12. The quality of the writing helped to hold my attention.	49%	35%	16%	0%	0%
13. This lesson is so abstract that it was hard to keep my attention on it.	0%	10%	22%	41%	27%
14. The pages of this lesson look dry and unappealing.	8%	11%	16%	30%	35%
15. The way the information is arranged on the pages helped keep my attention.	41%	49%	10%	0%	0%
16. This lesson has things that stimulated my curiosity.	52%	35%	8%	5%	0%
17. The amount of repetition in this lesson caused me to get bored sometimes.	16%	27%	11%	32%	14%
18. I learned some things that were surprising or unexpected.	46%	35%	14%	5%	0%
19. The variety of reading passages, exercises, illustrations, etc., helped keep my attention on the lesson.	51%	28%	16%	5%	0%
20. The style of writing is boring.	11%	5%	24%	41%	19%
21. There are so many words on each page that it is irritating.	11%	5%	11%	41%	32%

thought that the experience of virtual reality supported the remote access to laboratory practice was remarkable.

The third dimension of the study, "Satisfaction", was measured with 6 questions. All the participants were highly satisfied, for the average score for this dimension was 5 out of 5. The processing of the VR-based course developed with VRRALAB design was, hence, very satisfactory.

When the questions between 22–27, as seen in Table 6, are considered, where the Satisfaction dimension is measured, 89% of the participants gave a satisfactory completion of the exercises in the lesson (Q22) However 92% of the participants liked the lesson, wanted to learn more (Q23) and enjoyed working with VR. Only 8% found not enjoyed working with VR. 97% of the participants find it enjoyable to work with VR application, while 3% do not know whether it is enjoyable or not. (Q24). Likewise, 86% of the participants feel rewarded for the feedback given after the exercises (Q25). This result shows the importance of designing VR application with feedback based exercises. After completing this lesson, the rate of those who feel successful has appeared as 84% (Q26). Finally, 97% of participants find it enjoyable to work on a well-designed VR within a blended learning framework, while only 3% do not know if they can find it enjoyable (Q27).

When the frequency distributions of the questions measuring the Satisfaction dimension are examined, it is concluded that the vast majority of

Table 6. Questionnaire Satisfaction dimension questions and experiment group answer percentages

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
22. Completing the exercises in this lesson gave me a satisfying feeling of accomplishment.	57%	32%	0%	11%	0%
23. I enjoyed this lesson so much that I would like to know more about this topic.	65%	27%	8%	0%	0%
24. I enjoyed studying through VR.	59%	38%	3%	0%	0%
25. The wording of feedback after the exercises, or of other comments in this lesson, helped me feel rewarded for my effort.	57%	29%	14%	0%	0%
26. It felt good to successfully complete this lesson.	65%	19%	16%	0%	0%
27. It was a pleasure to work on such a well-designed VR in blended learning framework.	65%	32%	3%	0%	0%

Table 7. Questionnaire Relevance dimension questions and experiment group answer percentages

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
28. It is clear to me how the content of this material is related to things I already know.	46%	41%	13%	0%	0%
29. There were stories, pictures, or examples that showed me how this material could be important to some people.	49%	43%	8%	0%	0%
30. Completing this lesson successfully was important to me.	68%	30%	2%	0%	0%
31. The content of this material is relevant to my interests.	57%	24%	16%	0%	3%
32. There are explanations or examples of how people use the knowledge in this lesson.	59%	25%	16%	0%	0%
33. The content and style of writing in this lesson convey the impression that its content is worth knowing.	51%	38%	11%	0%	0%
34. This lesson was not relevant to my needs because I already knew most of it.	11%	16%	27%	14%	32%
35. I could relate the content of this lesson to things I have seen, done, or thought about in my own life after experiencing VR.	51%	33%	8%	3%	5%
36. The content of this lesson will be useful to me.	70%	27%	3%	0%	0%

the participants were satisfied with the processing of the VR-based course developed for the virtual reality supported by the remote access to laboratory design.

The last dimension examined in this study was the "Relevance" dimension and it was measured with 9 questions. The participants reported an average of 4 out of 5 for this dimension. Hence, the results indicate that the students who participated in this study exhibited a high level of interest for the course in which the VRRALAB application was used.

When the responses to the questions between 28-36 in Table 7, which constitute the Relevance dimension, are examined, 87% of the participants think that the content of the course material is clearly related to the topics they know (Q28). 92% of participants state that there are stories, pictures and examples that show how this material might be important to some people (Q29). 98% of the participants state that it is important to successfully complete this course(Q30). Those who think that the content of this material is related to their interests are 81% (Q31). Similarly, 84% of the participants stated that there are explanations and examples of how information is used in this lesson (Q32). 89% of the participants think that the content and writing style in this course gives the impression that the content of the subject is worth knowing (Q33). This result reveals the importance of the content and shape for the course material for students. 46% of the participants think that this course is related to their needs, while 27% think that it is not about their needs (Q34).

When the findings relating to the dimension of Relevance are analysed, it is clear that the levels are quite high for the students who used the virtual reality supported remote access laboratory application.

5. Conclusions

Educational structures in engineering and technology require applied laboratory studies. It is observed that the need for remote access virtual reality laboratories will increase further in the face of population growth, insufficiency of media, low limited number of material types, increased costs and especially in extreme crisis situations, such as the COVID-19 pandemic. In order to overcome the difficulties of providing the necessary physical environments to adapt to the developing technologies, there is a need to develop virtual laboratories in terms of increasing the sense of reality. These will provide an effective working environment for existing lessons, or they can be complementary or alternative depending on the course structure and learning objectives. Virtual environments go beyond the usual and offer a new "reality", one that is different from the existing order and rules. This reality requires looking at the usual world and rules from a new perspective, which will enable effective solutions to problems in many areas. Virtual reality environments emerging alongside the internet-based work areas can increase the effectiveness of applied courses by enhancing the sense of the reality of current remote access.

The purpose of this study was to design and implement a VRRALAB in PLC training. The aim was to realise virtual reality technology via mobile systems and to allow access to users. The unique and innovative aspect of this study is the development of a mobile-based application with remote access and virtual reality support during PLC training. Whilst in previous studies on remote access lab designs have been implemented, these did not constitute virtual reality supported mobile based applications. Mobile access, in particular, is becoming one of the most important issues of today; a lab that is suitable for students to access from anywhere. It has also been demonstrated that our design increases student success over traditional methods. In sum, with VRRALAB, the users can gain access from anywhere and participate in the course. Moreover, this application could be used in many lessons besides PLC ones in the future.

As a result of this study, which involved developing the VRRALAB application, a 4-layer system architecture was devised comprising a: user layer, virtual objects layer, real time stream layer and physical objects layer. This structure is a key output, for with this structure, it is possible to develop remote access and virtual reality supported applications for any course. In the presented case, an IP camera has been used for the purpose of PLC, raspberry pi and relay card with internet technology of objects, power supply and real-time monitoring of the system. Control and communication protocols were used for the control of physical equipment. A virtual reality supported model library was created, with an interface being designed to control virtual and physical objects in this library via an Android based phone. The android application created with the designed interface was provided to the students to download to their phones and tablets with the help of a square code via the presented lecture notes. Within a traditional PLC course, the virtual reality supported laboratory application with remote access was tested on students for a 4-hour course. The efficacy of VRRALAB was evaluated with a comparative assessment of experimental and control groups along with the "Instructional Material Motivation Scale" questionnaire being given to the former group. According to the assessment, the experimental group students were 45% more successful than the control group students. This result shows the positive effect of the VRRALAB application on student success.

Regarding the results of the motivation questionnaire, these revealed that a lesson supported by virtual reality using an internet-based remote laboratory application increases the reliability rates, attracts more attention and has a high level of satisfaction. The average score for the confidence of the participants was found to be 4 out of 5. (80%). This shows that a VRRALAB application course is likely to increase confidence among participating students. For the attention dimension, the participants registered an average of 4 out of 5 (80%). They reported finding the VRRALAB application experience beneficial in attracting their attention to the course associated with it. The study's third dimension, "Satisfaction," was gaged with six questions. All participants were extremely satisfied with an average score of 5 out of 5 (100%) for this dimension. The last factor explored in this analysis was that of "Relevance,", which was measured with nine questions, for which the participants were shown to have an average of 4 out of 5 (80%), which is also high. In sum, it has been shown that VRRALAB can be implemented successfully with the proposed 4 layered structure.

The sample in this study was limited only to the second year students of a PLC course in a university in Istanbul, Turkey. Results can be different in different universities, programmes, and countries. Therefore, these findings need to be interpreted bearing that in mind. The reason why only mechatronics students were chosen is that PLC education is one of the courses that have a key role in this programme. The number of 3D models in the virtual objects library is one limitation of this study, whilst budget and time constraints constitute other shortcomings of the research.

In future studies, the aim will be to increase the impact and examine the effects on vocational and technical education by developing training laboratories for other virtual reality supported remote access course subjects, which are planned to be developed in line with this study. Moreover, we consider that it would be beneficial to investigate the effect of unearthed system architecture on evaluation processes by integrating it into distance education systems.

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Appendix A: Exam Questions

<table>
<tr><th></th><th>No Question</th></tr>
<tr><td rowspan="2">1</td><td>Which of the following is an acronym for PLC?</td></tr>
<tr><td>(a) Programmable microcontrollers (b) Programmable microprocessors (c) Programmable logic controllers
(d) Program logic doors (e) Electromechanical control.</td></tr>
<tr><td>2</td><td>Draw the simple structure of the PLC.</td></tr>
<tr><td rowspan="2">3</td><td>Which of the following is not one of the main features that distinguishes PLC from other control systems?</td></tr>
<tr><td>(a) Reliable (b) Less space and less downtime (c) Requires less cable connections
(d) Status of inputs and outputs cannot be monitored (e) There is the possibility of using ready functions.</td></tr>
<tr><td>4</td><td>Write the PLC hardware parts.</td></tr>
<tr><td rowspan="2">5</td><td>Which of the following symbols is normally open contact?</td></tr>
<tr><td>(a) —| |— (b) —(R)— (c) —| / |— (d) —( )— (e) —|NOT|—</td></tr>
<tr><td rowspan="2">6</td><td>Which of the following symbols is a normally closed contact?</td></tr>
<tr><td>(a) —| |— (b) —(R)— (c) —| / |— (d) —( )— (e) —|NOT|—</td></tr>
<tr><td rowspan="2">7</td><td>Which of the following symbols is output?</td></tr>
<tr><td>(a) —| |— (b) —(R)— (c) —| / |— (d) —( )— (e) —|NOT|—</td></tr>
<tr><td>8</td><td>Draw a ladder diagram for the circuit that will continuously activate a lamp with a button and turn it off with a button.</td></tr>
<tr><td>9</td><td>Draw a ladder diagram for the circuit that will continuously switch on a lamp and a fan with sensor information and switch it off with a button.</td></tr>
<tr><td>10</td><td>Draw a ladder diagram for an electric motor circuit with two limit switches, working by ensuring that a water tank is filled when it is empty and stops when it is full.</td></tr>
</table>