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An Automated Measuring Laboratory (VMLab) in Education*

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This paper presents and describes the opportunities for new technologies applied in the field of technical education. Specifically, it introduces VMLab system characterized by implementing tools of new Internet trends in measurement technology. Because this system is available to anyone who has an Internet connection, it belongs to the top ways of obtaining practical education. Student using this VMLab system for e-Learning is to be helped to create simple or complex electrical connections. He/she selects the individual devices and components from a previously defined library. These allow users to compose various electric schemes and to make their measurements according to the teacher's instructions. From the educational point of view there is a great benefit for students that they can learn to work with real devices even without having them physically available. Therefore, this system can be used without time, space and economic limitations. It means it is very useful for the education of all motivated and talented students, regardless of their social background.

Keywords: VMLab; variable topology; e-Learning; Internet; technical education, for all

1. Introduction

The educational process in most of the engineering studies also involves laboratory experiments. Laboratory work is especially mandatory in electrical engineering. Laboratory environment in the engineering studies provides students with opportunities: to test conceptual knowledge, to work collaboratively, to interact with the equipment, to learn by trial and error and to perform analysis of the experimental data. Rapid progress of the Internet and computer technology, along with its increasing popularity, enables the development of remote laboratories that support distance laboratory courses, where the experiments can be accessed, monitored and controlled remotely [1, 2]. IT technologies are often involved in modern measurement methods. A similar kind of technology has been enormously useful for encouraging students to use all ways of advanced innovation, design, simulation and computer-aided manufacturing technologies. It helps students to look closely at the conceptual aspects and to handle the tools that are increasingly required by industry [3]. With evolution of these methods, "remote" and "computer-supported" laboratories were implemented.

There are various types of laboratories in the concept of e-learning. They can be divided into three main groups [1]: standard, virtual and remote laboratories.

Standard laboratories represent real laboratories controlled and supported by educated academic staff. The usage of such laboratories is based on a physical interaction between the person measuring and the measurement system. The measured objects and measuring devices are contained at one place and can be represented e.g. by scientific research laboratories or didactic laboratories at universities. Such laboratories are based on collaboration of more users at one place, for instance, more scientists working together in one laboratory or a lecturer teaching students how to measure electrical quantities. And also due to this fact standard laboratories are less safe in terms of occupational health and safety compared to virtual and remote laboratories. Standard laboratories are also considered high-cost, as hardware resources need to increment in parallel with the increasing number of users.

Pure virtual laboratories are designed to simulate conditions of the real laboratory environment. These laboratories do not contain any physical objects except for a computer, but are represented by software, and thus are considered as low-cost compared to standard laboratories. The software varies depending on its use and the creator. Computer programs like OrCAD with PSpice or MATLAB and Simulink are a typical example of such laboratories. OrCAD is software that lets users create custom electrical parts and circuits, measure electrical voltage, current or power and display signals using PSpice simulation environment. The most striking difference between the pure virtual, standard and remote laboratorie*s* is that pure virtual laboratories return idealized values of measured physical quantities of subjects. Virtual laboratories are also considered a poor substitute

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for standard laboratories due to the absence of measuring hardware.

The term *remote laboratories* refer to a set of hardware and software used to perform measurements controlled remotely, over some geographical distance and with the ability to return (or display) measured data to users using communication networks. Modern remote laboratories are based on the client/server network structure. The client asks the server for data and the server answers. This is the only structure which ensures user-friendly usage of these systems, because clients only acquire information when they need it.

Technical possibilities of remote laboratories have evolved together with used technologies. Remote measurement laboratories may vary in modifiability level. According to the modifiability, we can divide remote laboratories into the following groups [4]: non-modifiable, half-modifiable and fully-modifiable remote laboratories.

The term *non-modifiable* remote laboratory refers to laboratories where users (positioned on the client side) are not able to modify any input values of the measurement. Users can only start the measurement and view the output values. These laboratories are used to determine the current status of an object. Remote laboratories measuring environment temperature or atmospheric pressure are a perfect example. It is quite common nowadays and could be referred to as telemetry.

Half-modifiable remote laboratories are laboratories enabling the user to change the input values of the measuring system. However, the user cannot freely add or remove the components of the measured system. This means the client is able to modify physical quantities (e.g. input value) and certain parameters of components of the measured system. Examples include moving valves, changing range or input values of measuring instruments or changing the resistance.

Fully-modifiable remote laboratories are laboratories enabling the user to fully modify the measured system. The client is able to change the input as well as add or remove components of the system based on variable connections. Electrical relays are often used to supplement these features. For example, the client can build custom electrical circuits only limited by the set of available components and then perform measurements. Fully modifiable laboratories represent the highest technical solution. There are only few really fully modifiable remote laboratories, VMLab being of them.

VMLab system has been developed at the Department of Theoretical and Industrial Electrical Engineering (abr. DTIEE) at the Technical University of Košice as a result of the research project. It was primarily designed to teach of subjects in the field of electrical measurements. Its options were subsequently extended and the system was made available to any party interested in gaining knowledge in the given field. The main motivation for creating such a system was a need to save time. As every university institution involved in the teaching process, DTIEE also deals with laboratory time consumption. A typical situation in the classroom would be one teacher leading 12–15 students during the lesson taking place in the laboratory. All the students have a common task: to connect a circuit and measure certain parameters of the circuit. Due to lack of time, equipment and personnel, only a few students usually get a chance to create the circuit. Most of the students will only become observers. DTIEE treats this as a big mistake, because these observing students are missing practical knowledge.

Another great motivation that led DTIEE's staff to create VMLab system was an initiative to include e-Learning methods in the practical exercises of Practical Electrical Measurement. The Internet is nowadays widely used when it comes to e-Learning methods as a mainstream tool for providing education based on study materials given to students in the electronic form. The DTIEE has tried to improve e-Learning methods even more, so that it would not only bring theoretical information in the field of electrical measurements, but also help students learn to use real instruments in electrical engineering. Moreover, the advantage of such e-Learning method—VMLab system is that the students can also easily perform measurements from home, which does not require a teacher to be present and/or laboratory to be available and there is no danger of electric shock. Students engage in a truly realistic work with electrical appliances remotely, using just the Internet. Another great benefit of this system is that it eliminates the burden of teachers and mainly of the measuring equipment which can occur especially when the equipment is manipulated and connected by students. VMLab system included in the teaching process reduces the cost of the maintenance of measuring instruments due to faster wear when used in physical measurements. Funds saved by this can be invested in the modernization of the VMLab system. In this way students would have access to new devices to which they would usually have no access, because they are costly or potential damage to such devices would be costly for the department [5–9].

The VMLab system as an e-Learning tool for teaching subjects in the field of electrical measurements could be available to anyone on demand, the Internet connection being only condition. One of the greatest benefits of this system is that is can provide clear demonstration of how to use and connect electrical devices and create circuits and schemes. Moreover, it greatly contributes to education of those students whose economic situation does not allow them to attend courses, of active students and the students with physical impairment.

2. Architecture of VMLab

VMLab is an abbreviation of the Slovak title '**V**zdialené **M**eracie **Lab**oratórium' that means Remote Measurements Laboratory in English. It consists of three main parts: client, server and real laboratory devices table. Its architecture can be seen in Fig. 1.

Real laboratory devices table consists of electrical components, e.g. resistors, coils, condensers and measurement devices, e.g. voltmeters, ammeters, watt meters and power supplies. All the components and devices are connected to interconnection bus (specially designed for this purpose) that is controlled by the server. Client can connect to the server using client program from anywhere in the world. The access point to the Internet is the only condition. One can create an electrical circuit virtually and send the circuit topology to the server. The server sets the real laboratory devices table according to the circuit scheme via LPT (Line Printer Terminal—parallel port) and a real electrical circuit is composed. All the measured data from measuring devices are collected to the server via USB and sent to the client. The user is also able to set voltage value on the manageable power supplies. Users are using the client part of the VMLab software. Students worldwide or also external company employees within the possible commercial use of the VMLab technology can take the role of the user.

VMLab represents a fully operational prototype of the technology under the protection of the Patent Office No: 288241 of Slovak Republic [5].

3. Description of VMLab function

In the beginning, the client connects to the server and asks it for available electrical components. The server replies with a set of components and devices connected to the real laboratory devices table. A server database may contain a number of components and devices possibly connectable to the devices table. However, not all defined devices and components are available at one moment.

After the client receives the available set, the user can start to design an electrical circuit scheme. One can only use devices and elements from the set that is available and create the circuit scheme and assemble it using the devices and connecting elements. Client part interface can be seen in Fig. 2.

Students can use several types of electrical circuit's components. The first type is passive dipoles shown in Fig. 3(a). The passive dipoles include e.g. AC or DC meters (voltmeter, ammeter), coil, resistor, etc. Another type is passive multipoles shown in Fig. 3(b). Multipoles are the components with more than two poles, e.g. wattmeter or impedances already connected to a star or delta formation. There are also active electronic components, as seen in Fig. 3(c). All power sources connected in VMLab device table are manageable. Therefore, the user may change power source voltage during the measuring process. Another type of electric scheme components are the conductors. Fig. 3(d) shows an example of available conductors. In this case conductors are the graphical symbols used to create a connection between the electronic components mentioned above. The user can design an electric circuit by VMLab client program using all types of electronic components. An example of a final design of an electrical circuit is shown in Fig.3(e).

After the client completes the virtual electrical circuit, he/she tries to log on the VMLab server. No authentication is necessary to receive an available set of connected devices. However, to assemble a real electrical circuit, authentication is required. Only one client at the time is allowed to be connected to the server using the authentication. If the server is busy, the client has to wait. After successful authentication the client sends a virtual circuit scheme to the server. Then the server sends instructions to the VMLab devices table and a real electrical circuit is assembled according to the virtual

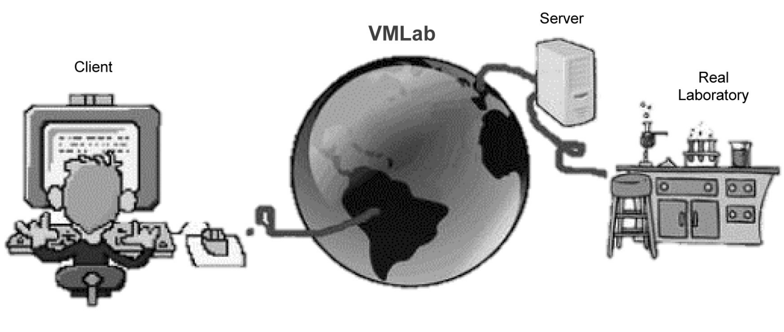

Fig. 1. VMLab architecture.

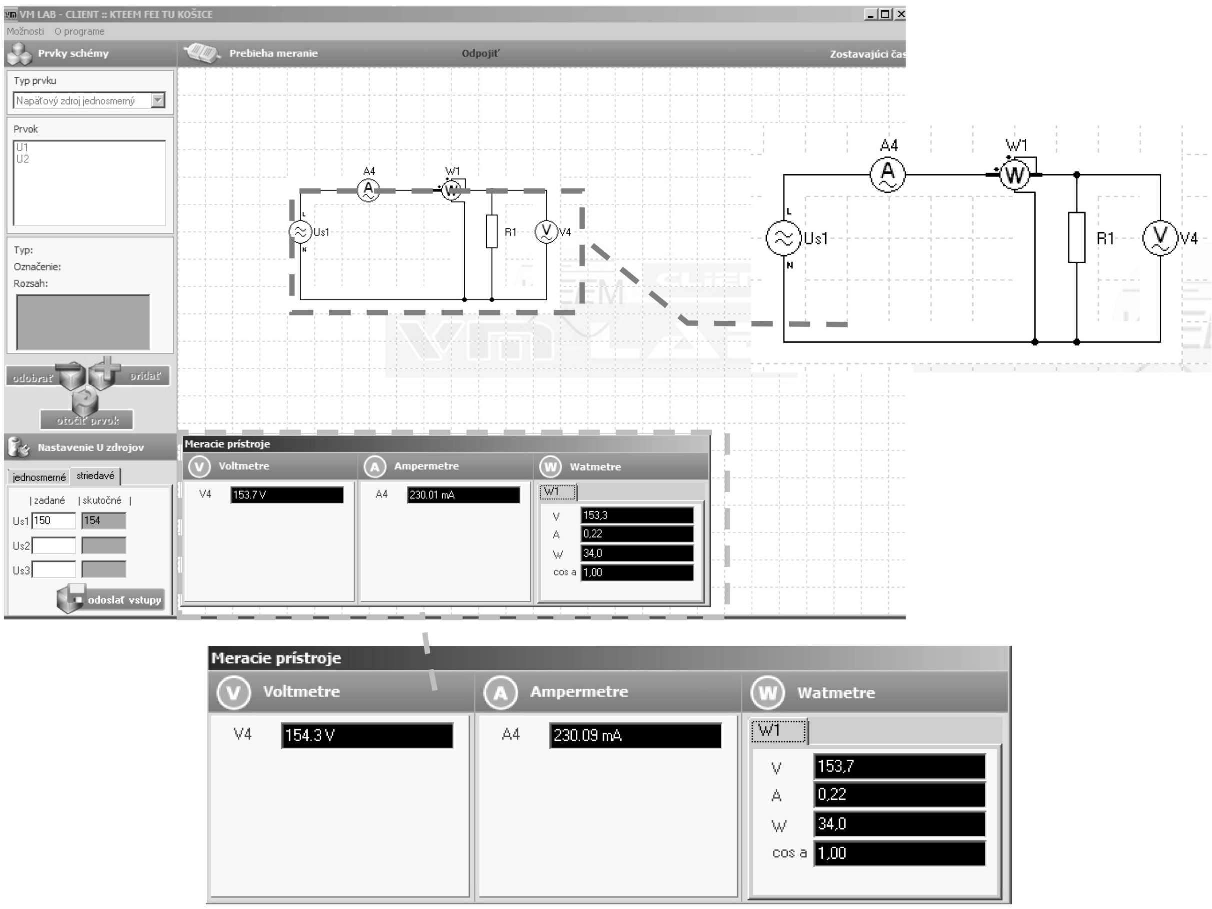

Fig. 2. VMLab client part.

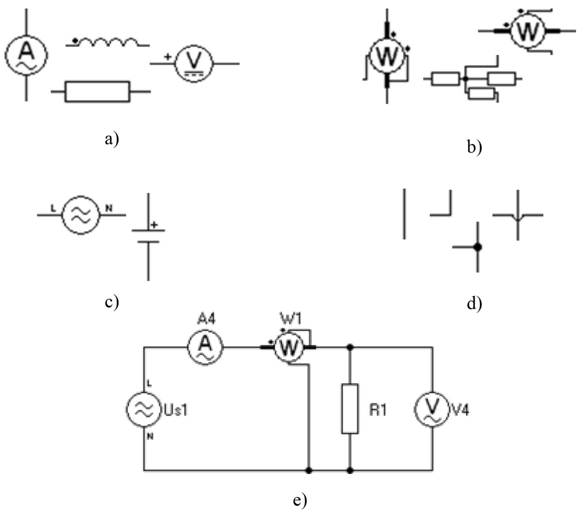

Fig. 3. (a) Passive dipoles, (b) Passive multipoles, (c) Active components, (d) Conductors example, (e) Electric circuit example.

scheme. Instructions are sent by the LPT port. Data from the measuring devices are received via USB/RS232 port and forwarded to the client. The user can see data from all the measuring devices used in the scheme (Fig. 2) and real equipment (shown in Fig. 4). The user can also change the voltage of the power supply to see what influence it has on the output parameters. The VMLab system is able to read the information of the steady state in real time.

The existing VMLab prototype is actually intended for courses of basic electrical measurements such as: voltage, current, resistance, inductance, capacitance, active and reactive power measurements and application of serial and parallel connections. The specialization of the VMLab may vary. The actual specification depends on the components and devices connected to the devices table.

As mentioned before, the VMLab is based on a patented technical solution and presents a fully customised solution of a remote laboratory. Many remote laboratories are based on the existing hardware solutions [4] (for instance Matrix Switch Modules from National Instruments) or software solutions (for instance LabView, etc.). The existing VMLab prototype supports up to 64 connection points and handles up to 16 different connection nodes. This is the limitation of the prototype only. If necessary, the capacity can increase using the VMLab technology. Another advantage of this custom solution is the maximal current. A standard remote laboratory handles current up to 200 mA [4].

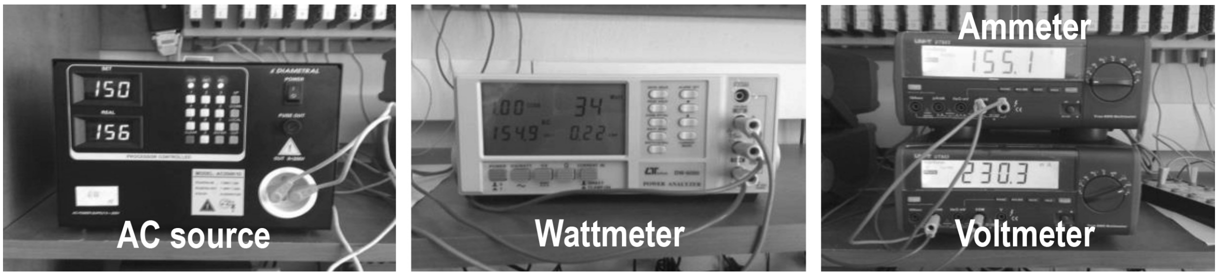

Fig. 4. Devices of the measured electrical circuit.

Table 1. Comparing a standard laboratory and a remote laboratory in electric measurements lessons

	Standard Laboratory	**Remote Laboratory**
Assembling electrical circuits by students	• physical presence of students is required • can be done locally only • while the circuit is being assembled, the laboratory is occupied • laboratory conductors are required	• can be done from different remote locations • physical presence in the laboratory is not required • while the circuit is being assembled by a student, the laboratory is not occupied • laboratory conductors are not required
Electric measuring process	• possibility of device damage when incorrectly used • the possibility of injury to students - electric shock • slow measuring process • possibility of subjective measurement mistakes occurring	• devices can be protected by remote laboratory limitations • no danger of electric shock • fast measuring process • impossibility of subjective measurement mistakes occurring

Currently, the devices and components connected to the VMLab table handle up to 600mA. However, the VMLab table is designed to handle measurements up to 10A. If necessary, this limitation could be shifted to higher current using different components. Therefore, the VMLab solution is unique and universal for wide range of courses in engineering education.

4. Educational and indirect economic benefits of remote laboratories

The main educational benefit of the designed VMLab system is that all its specialized apparatus is available to anybody via the Internet without any space and time limitations. This makes the whole educational process more effective and it can provide students with more of new knowledge in a shorter period of time [6, 7]. Fig. 3(e) displays a connection which was one of the students' educational tasks. Most of the students' tasks in electrical measurement process consist of two parts: to build an electrical circuit and to perform multiple measurements under specific conditions. The real laboratory connection (by which we mean the assembling time) of such an electrical circuit, in which students should state the amount of electrical power given by the input AC source to the resistive load, takes approximately 10 minutes. The measuring itself takes additional 5 minutes. While measuring, students read measuring devices value, changes voltages on power supplies and observe the differences. Table 1 contains several aspects of the comparison of standard and remote laboratories of electrical measurement.

One student takes approximately 15 minutes to complete the whole measurement process (10 minutes of assembling a circuit and 5 minutes of measurement). Students design electrical circuit at their own computers when using the VMLab. When designing electrical circuits, no real devices are used at the laboratory. All students can design electrical circuits at the same moment. Real devices in the laboratory are used only in the process of measuring. Only one student can perform the measuring at one moment.

As mentioned in Table 1, when assembling electrical circuits, the remote laboratory is not occupied. Therefore, there is a linear time difference between standard and remote laboratory occupation depending on the number of students. This time difference is shown in Table 2.

As shown in Table 2 and Fig. 5, electrical measurement course for 20 students requires 5 hours of standard laboratory time but approximately 1.6 hour of remote laboratory time. Disassembling created circuits takes further time. It could be minutes in a standard laboratory, but a remote laboratory does it automatically in a few seconds.

It is evident from the data presented in Table 2 that the educational process in the VMLab takes significantly less of the laboratory time than the

Table 2. Comparing laboratory occupation time

Number of students	Standard laboratory occupation time (minutes)	Remote laboratory occupation time (minutes)
1	15	5
2	30	10
3	45	15
4	60	20
5	75	25
10	150	50
15	225	75
20	300	100

Graphic representation of data in Table 2 is shown in Fig. 5.

present education using classical forms (the time spent on safety procedures was not taken into account in either of the cases). It proves that this method of education is more effective than the classical approach. Moreover, effectiveness is also obvious from the teacher's working time. Using the classical approach, it is approximately 8 hours. However, using the VMLab it is possible to perform the measurements at any time during the day, within 24 hours which means 3 times longer in comparison to the classical methods [8, 9].

The VMLab remote laboratory can be mainly

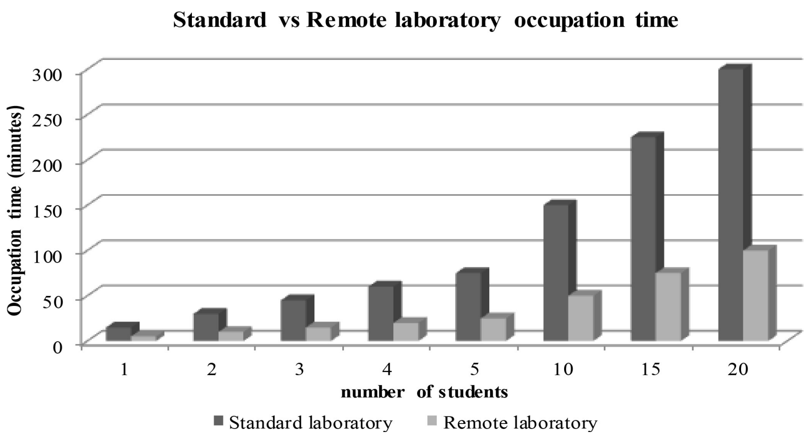

Fig. 5. Comparing laboratory occupation time depending on the number of students.

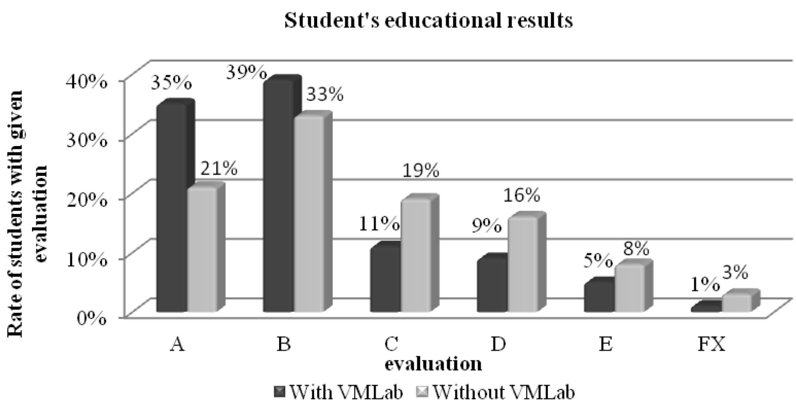

Fig. 6. Graphical representation of final students' evaluations.

Questionnaire

	0	1	2	3	4	5
a) To what extent can working with the VMLab substitute the work at a real laboratory?	☐	☐	☐	☐	☐	☐
b) To what extent did you fear damage of something in the VMLab?	☐	☐	☐	☐	☐	☐
c) To what extent has using the VMLab variable property improved your learning process?	☐	☐	☐	☐	☐	☐
d) To what extent has the on-line access to the VMLab made your learning process easier?	☐	☐	☐	☐	☐	☐

Check your answer with an **X**. 0 means none extent and 5 means completely.

Fig. 7. The layout of the used questionnaire.

Table 3. The evaluation of the questionnaire in per cent

	The question	0 (none)	1 (20%)	2 (40%)	3 (60%)	4 (80%)	5 (completely)
(a)	To what extent can working with the VMLab substitute the work at a real laboratory?	2%	10%	16%	29%	39%	4%
(b)	To what extent did you fear damage of something in the VMLab?	74%	10%	6%	6%	3%	1%
(c)	To what extent has using the VMLab variable property improved your learning process?	0%	4%	10%	13%	18%	55%
(d)	To what extent has the on-line access to the VMLab made your learning process easier?	1%	3%	4%	6%	22%	64%

used as an additional tool in electrical measurement lessons or it can be used partly as the main tool in teaching subjects from the field of electrical measurement. It is appropriate for students whose physical presence in the laboratory is problematic—external students, distance learning students, etc. Using the VMLab as an additional learning tool has had a positive influence on the final ranking of students taught. Fig. 6 compares the assessment of the students before and after they used the VMLab as an additional tool. The assessment is based on an international scale where A (100%–91%) represents the productivity range from 91% to 100% and similarly B (90%–81%), C (80%–71%), D (70%–61%), E (60%–51%), FX ($\leq$ 50%).

Positive user feedback has also been obtained from the responses contained in a questionnaire survey done among 87 graduate students. The template of the questionnaire used is displayed in Fig. 7. The above-mentioned students were graduates of the subject of Electrical Measurement. They were divided into 7 educational student groups ranging from 10 to 13 students. During one semester, they receive 3 hours of daily from of education in a real electrical measurement laboratory (1 semester = 13 weeks).

They only employ the VMLab lessons as an additional learning tool in the course of home layout solving as they work on tasks at home.

Detailed data evaluations of questionnaire survey are included in the next Table 3.

Fig. 8 shows the graphical interpretation of the students' answers.

Drawing from all the obtained results it is evident that students in vast majority understand the use of such a remote laboratory as a strong and positive tool and they recommend it as part of the educational process. Allegedly, the most appraised properties of the VMLab are the speed of the electrical circuit interconnection and measuring, variability,

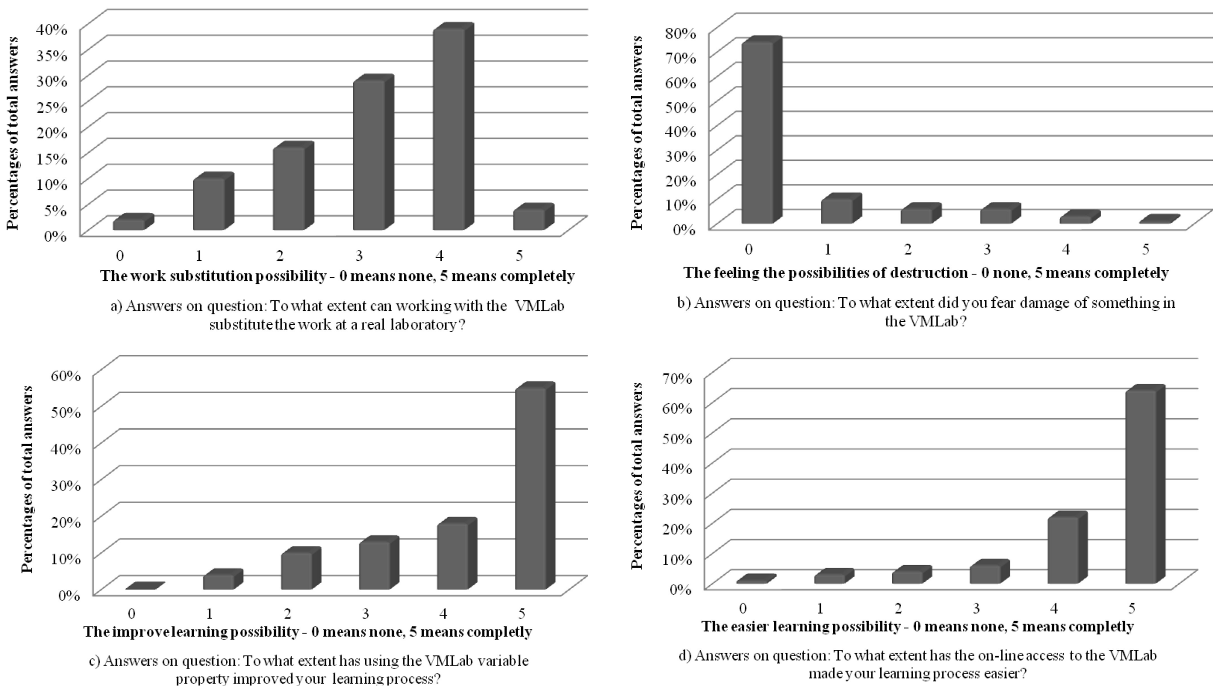

Fig. 8. Graphical interpretation of the students' answers.

Table 4. Comparing indirect economic advantages and disadvantages of standard and remote laboratories

	Standard laboratory	Remote laboratory
Usage of measurement devices and components / laboratory	• max. 8 hours per day • max. 5 days a week	• 24 hours a day • 7 days a week
Presence of teacher during the measurement process	yes	no
Possibility of equipment damage	• higher, when students handle the equipment directly	• lower (as the remote laboratory software protects devices against inappropriate use)
Laboratory room requirements	• suitable furniture equipped • meets hygiene requirements • higher cleaning costs	• furniture for students not required • no special hygiene standard required • lower cleaning costs
Software and hardware additional cost requirements	• no additional software or hardware required	• special hardware and software for remote laboratory required

electrical security and permanent on-line availability. Such a conclusion can be drawn from their educational results, which have markedly improved (Fig. 6).

The economic benefits of the remote laboratory are also undeniable. Financial savings depends on the remote laboratory hardware cost, software cost and of course components and devices used directly in the educational process at the remote laboratory. In case of the VMLab, the software and hardware part of it was developed by researchers and students of the Technical university of Košice so production costs were only paid. Table 4 compares the indirect economic benefits of standard and remote laboratories.

Due to the above stated higher effectiveness of educational process using the VMLab (in comparison with the classical methods of education) it is possible to provide more knowledge, skills and offer better and wider expertise to all students using this modern approach. The remote laboratory allows implementation of real electrical measurements also in e-Learning systems supporting the worldwide distance learning [10–15].

5. Conclusion

An increase in number of students, making the education process more efficient for students who cannot attend lectures in person (economic situation, physical impairment, distance, etc.), as well as providing high quality of practical education of technical skills for talented students had been the impulse to develop a new e-Learning platform called the VMLab remote measurement laboratory. This laboratory allows connection and measurement of various electrical circuits remotely via the Internet as the main communication bus. The main advantage is in the unlimited (24hours/7days) availability of the laboratory to all the motivated students who are interested in solving their projects beyond the frame of direct education and classical approach. This laboratory can also be accessed by the students from other universities or by the non-profit organizations which provide education e.g. in developing countries (naturally, upon mutual agreement).

This e-Learning system can be very useful also in the commercial sphere. It can serve as a retraining tool for technicians or for specialized measurements. For example, if certain companies need to measure some specific connection and it does not possess all the necessary equipment for such task, it can send the sample to be measured. This sample can be then connected to the VMLab and measurements can be done.

Other universities also possess similar systems to the VMLab. However, the VMLab is unique, because it allows the arbitrary connections. The only limitation from the user's point of view is the library of devices. The other similar systems do not offer such an option. They only allow the measurements of pre-defined schemes, or the user has a very limited opportunity to customize the measurement. In the VMLab system, the student has a nearly unlimited range of schemes creation. This makes the VMLab one of a kind. This advantage is widely used in the e-Learning process. The teacher has the possibility to create arbitrary tasks, which makes the learning process more effective for the students.

Although the remote laboratory is a very big advantage, working with it cannot fully replace the experience obtained in a real laboratory. Even so, remote laboratories are a step forward compared to virtual laboratories with idealized calculations. They allow the students who cannot physically attend the courses to obtain the same amount of experience.

Students' experience does not include direct handling of the measurement devices, but they obtain experience with real measurement itself. Real measurement contains measurement errors and inaccuracies caused by multiple factors such as: measurement devices accuracy class, contact resistance, environment influence etc. These errors and inaccuracies are absent in simulations and idealized calculations. In the real world students will face these inaccuracies and they need to know how to deal with them.

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