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EXPLORING VIRTUAL LABORATORY TECHNOLOGY IN ELECTRICAL/ELECTRONICS ENGINEERING TRAINING.

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ABSTRACT
Electrical and Electronics Engineering disciplines are technical specialties in which the learning process requires theoretical analysis, practical calculations and experimental studies. Practical laboratory training is generally favoured as a means of consolidating analytical and practical skills. However, the rapid development of new tools and electronics necessitates that laboratories be constantly updated and improved. This calls for sophisticated and expensive laboratory setups. Also, some modern equipment are complicated, require high skills and little adapted for student use. Overcoming some of these challenges of traditional laboratories is only possible with the use of virtual laboratory technology. This explores laboratory practice using modern information technology in the form of virtual laboratories, to develop laboratory platform that provides practical assistance to educators to conduct practical classes for Electrical Engineering courses. The research methodology adopted in this study is qualitative and exploratory in nature, as it is aimed at identifying, understanding, and implementing an optimum virtual laboratory platform within Electrical engineering context.

Keywords: virtual, simulation, laboratory, software, competency

1. INTRODUCTION

Pursuant to PNDC Law 321 of (1992) on polytechnics (the Polytechnic Act), with subsequent changes (the Polytechnics Act 745), Ghana's polytechnics were upgraded to tertiary institutions to promote practical training in manufacturing, technology, applied science and commerce (Ansah, 2012; Agyefi-Mensa and Edu-Buandoh, 2014). In view of this, the polytechnics' training programmes were to be hands-on and career oriented, hence the introduction of many Higher National Diploma (HND) engineering programmes, including HND in Electrical/Electronics. An important feature of the HND Electrical/Electronics Engineering programme is the large amount of laboratory practical training in the curriculum.

The value of practical laboratory experience for engineering education disciplines cannot be over-emphasized (Feisel and Rosa, 2005). Yet ensuring that this experience is up-to-date and relevant to the needs of industry remains a challenge. Training of students for operation and maintenance of electrical systems and equipment requires the organization of laboratory workshops that allow students to study the components of these systems and to acquire the relevant practical skills. The continuously changing dynamics of industrial practices, systems, equipment and tools poses technical institutions overwhelming challenges of implementation techniques of accelerated learning and continuous improvement of laboratory facilities. The creation of modern teaching laboratories requires considerable financial investments for the purchase of technical equipment, keeping them in working condition, and the development of teaching materials.

Trends in the development of high-tech, computerised industry, along with rapid changes in job functions and demands, requires the creation of a functioning system of continuous training of engineers, corresponding to the increasing requirements of high level of practical skills of modern industry.

Many Ghanaian tertiary institutions do not have the ability to purchase expensive electrical instruments and equipment (Nyarko, 2011). Therefore, students' access to advanced equipment

www.ajaronline.com Vol.2, No.2 (Pages 40-50) ISSN 2408-7920 (October 2015)
is severely limited. These difficulties have a negative impact on the quality of training of future electrical engineers. In this connection, much attention is paid to the use of innovative teaching methods, including those involving the use of virtual simulation technology.

Aim

The aim of the study is to investigate modern laboratory practice using information technology in the form of virtual laboratories, so as to implement an optimum virtual laboratory solution for the Electrical/Electronics Engineering Department of Cape Coast Polytechnic.

Objectives

To accomplish this broad aim, a number of specific objectives have been spelled out. They are to:

- Review existing constraints of the traditional approach to laboratory training in the Electrical/Electronics Department of Cape Coast Polytechnic.
- Explore the applications of virtual laboratory in technical education
- Identify effective deployment strategies, as well as the key factors that contribute to successful virtual laboratory technology deployment and integration.
- Implement a pilot-based virtual laboratory platform and carry out preliminary assessment of its viability as a tool for enhancing competency in Electrical/Electronics Engineering training.

RESEARCH METHODOLOGY

The study employed a qualitative research method to explore issues of developing and deploying interactive virtual laboratories. In this regard, the approach adopted in this study is exploratory in nature. Content analysis from existing literature was adopted in analyzing the data

2. OVERVIEW OF THE HND ELECTRICAL/ELECTRONICS PROGRAMME

2.1. Programme structure and objectives

The HND Electrical/Electronics programme is structured into three different specialisations and organised as a cohesive combination of courses. A course is a programme element which aims to give students a set of professional skills within a fixed time frame, and concluding with one or more examinations within specific exam periods. The programme is based on a combination of academic, problem-oriented and interdisciplinary approaches and organised based on lectures, classroom instruction, laboratory practicals, project work, and exercises.

The major aims of the programme, as stated in the syllabus document , NAPTEX (2002), are to enable students to:

- *Acquire knowledge and understanding of the concepts and principle of electricity and electronics.*
- *Acquire the proper techniques in the use of tools and equipment*
- *Apply their knowledge in the correct use of electricity to promote safe working procedures and safety precautions.*
- *Develop skills in the use of appropriate tools and electronics instruments in measurement, trouble shouting and repairs.*
- *Acquire the ability to prepare lay-out, install and commission industrial equipment and electrical services.*

It is obvious that a large amount of practical training is needed to achieve these objectives. Currently, practical skills are developed through laboratory experiments, industrial placements and field trips or educational tours.

2.2. Constraints of the traditional approach to laboratory training

Existing approaches to laboratory practical training, using a variety of experimental facilities and equipment in accordance with state accreditation standards, makes it necessary to use large amounts of expensive equipment. However, current economic conditions, increasing student numbers, along with high cost of procuring and maintaining physical laboratory infrastructure, have led to huge deficit in laboratory equipment and accessories in the Department. As a result, even though laboratory practicals are integral part of the Electrical/ Electronics Engineering programme, some laboratory practical sessions do not take place.

The increasingly large class sizes exert further pressure on the limited resources available. In most cases, students are limited in their interaction with the physical setups because of the large number of students sharing the setups.

Additionally, some of the laboratory objectives cannot be adequately met with traditional lab setups because of several technical constraints.

Furthermore, with the introduction of evening and weekend programmes, it has become imperative to explore and exploit alternative ways of students undertaking practical studies without necessarily using a traditional laboratory.

3. CONCEPT OF VIRTUAL LAB AND ITS APPLICATION IN ELECTRICAL ENGINEERING TRAINING

A virtual laboratory can be defined as a platform for conducting experiments through computer operation, simulation, or animation locally or remotely via the internet (Chan and Fok, 2009) Virtual laboratory technology involves the use of interactive software to simulate the behavior of real-world objects and processes in a computer learning environment that helps students acquire new knowledge and practical skills in a subject. A virtual laboratory is basically a computer application software consisting of computer models that simulate the operation of physical equipment (devices, components, instruments, panels, etc), under various conditions, and creating the illusion of the behavior of the real physical hardware.

As noted, use of traditional laboratories is generally favoured as a means of conducting practical training. With Electrical/Electronics Engineering, however, this can be challenging sometimes. There are a number of situations where laboratory tests involve significant costs for educational institutions. The use of virtual laboratories in educational process allows the trainee to experiment with equipment and materials that are not in the real laboratory. This enables him/her to gain practical skills in complex experiments and to familiarize with unique computer models of expensive facilities.

Also, it is not always possible for students to perform an experiment right the first time after theoretical training. Often, for a successful outcome, it is necessary to conduct an experiment several times. This may increase cost substantially. In such situations, it is necessary to save time and costs by first experimenting using special virtual simulators and later transferring to the real laboratory set-ups.

In addition to the hands-on practical experience provided by the Laboratory practical training, technical specialties require additional capabilities to analyse and process technical information effectively. This skill-sets are easier to acquire through virtual environment than with real laboratories (Duijsen et al, 2005). In real lab situations, measurement errors and external factors can distort results and interfere with the understanding of key concepts. To obtain ideal results, it can be useful to isolate and investigate only essential elements of the system under study. Sometimes, this is only possible in a virtual simulation environment. External factors and measurement errors can be simulated if necessary.

The use of virtual lab in relation to the real lab might be:

- Demonstrational, where the virtual lab is used to show the sequence of actions and expected results of a real lab (El-Sabagh, 2010).

- Generalization, where the virtual lab is used to clarify issues and formulate findings and carry out analysis of graphical and numerical results (Chen et al, 2011)
- Experimental, where the virtual lab completely replaces a real lab. This usually happens in cases where the real lab cannot meet a particular objective of training, is time consuming, too complex or too expensive to carry out (Duijsen et al, no date).

It is important to keep in mind that a virtual model shows the actual processes and phenomena in a more or less simplified form, stripping it from minor details and distractions, and allowing only important characteristics to be emphasized in the model.

4. VIRTUAL LABORATORY IMPLEMENTATION, DEPLOYMENT AND INTEGRATION

As established, practical laboratory work is a major component of engineering education. It is necessary for consolidating practical skills related to the profession. In its traditional form, it has a number of drawbacks: limited material resources and the tight time schedule for performing laboratory work; initiative and independence of students is limited. The use of virtual simulation tools allow training providers to, at least, partially overcome these challenges and increase the motivation of students in the study of engineering courses. The following sections outline the necessary ingredients for successful realization virtual lab objectives.

4.1. Virtual Laboratory Implementation and Deployment Strategy

In view of the drawbacks associated with traditional laboratory training, and in particular, the challenges outlined in section 2.2, the authors have undertaken to implement a virtual lab platform with the aim of overcoming the challenges. We have identified four key factors that contribute to effective virtual laboratory technology deployment: clearly-defined and understood course objectives; a well-streamlined virtual laboratory programme structure; intuitive and consistent user interface; clearly-defined lab modules and a clear and concise lab manual. To ensure balanced delivery of these ingredients, we have developed the following specific strategies:

- Defining a coherent deployment plan
- Selecting the optimum technology
- Effective Integration of virtual laboratory technology

4.1.1. Defining a Coherent Deployment Plan

Planning the rollout of a new technology such as a virtual laboratory application into an educational environment can vary greatly in its characteristics and complexity. The deployment approach can significantly affect the outcome of the application (Nilsson and Wene, 2001). With this in mind, we have developed a set of guidelines and principles that would help in addressing each step of the process. For the virtual laboratory platform to be effective, it is recommended that the implementation framework include the following principles:

- Ensuring that the virtual laboratory practicals meet the HND education standards and specific programme objectives.
- Ensuring consistency with requirements of appropriate accrediting agencies.
- Maintaining a strong focus on learning and teaching outcomes within a competency-based training approach.
- Finding and eliminating unnecessarily redundant materials and processes.
- Developing a flexible, innovative learning platform, that accommodates diverse student needs.

4.1.2. Selecting the Optimum Technology

Successful implementation of virtual laboratory system is based on the correct choice of software according to specific requirements. These requirements are determined by the needs of the student, teacher and accreditation bodies. Some of the major factors to consider when implementing virtual laboratory technology include user-friendly interface, interactivity, interfaces for integration with other tools, and cost (Duijsen, et al, nd). Technology training has to be intuitive and must meet the objectives of the training programme and reflect real labour processes that must be mastered.

Obviously, the development of an interactive an interactive virtual laboratory platform from scratch is a complex assignment, requiring substantial investment in time and resources. The complexity of this task is reduced by re-using off-the-shelf software modules. There are many virtual laboratory SWs available with different features and capabilities for Electrical and Electronics simulations (Mancharkar, 2013). Commonly available simulation software tools come in open source/freeware and proprietary software forms (Nehra and Tyagi, 2014).

Generally, Freeware and Open Source software are provided free of charge and can be downloaded, used, and copied without restrictions (Nimmer, 1997) and (Coll et al, 2008). From our analysis, the available freeware and open source software do not offer the richness of functionality and interactivity that our proposed virtual lab requires. Although these free virtual laboratory systems can be tweaked and extended, the time required for doing so is excessive. On this basis, open source tools did not meet the requirements of the project. On the order hand, proprietary software packages are generally commercial software products that are released under restrictive licenses (Nehra and Tyagi, 2014). Prominent in this class are PSpice, multisim, Labview and Matlab. The biggest drawback of these commercial systems is their high cost. Fortunately, most of these systems provide evaluation or student versions that are either free or very affordable, and can be used for student work, under certain restrictions. Proprietary software was seen to possess the most complete set of features and functionality that satisfy the goals of the project.

4.1.3. Effective Integration of Virtual Laboratory Technology

Besides providing the appropriate ICT infrastructure, the successful application of ICT in education, to a large extent, depends on the revision of curricula to assure integration, and enhancing trainers' capacity to integrate the new systems (Mereku, 2011). According to Hallow (2011), the application of ICT in African educational systems does not often achieve the intended goals because of a lack of commitment and effort in ensuring effective utilisation and integration. Despite their invaluable benefits, educational software tools are also easy for misuse (Deken and Cowen, 2011). To avoid these pitfalls, we have developed a comprehensive integration framework that addresses the entire virtual laboratory design, implementation and utilization process.

The implementation of this framework requires compliance with the following conditions:

1. Identifying and realigning the laboratory practical resources from the current general system to support the new virtual technology
2. Streamlining of laboratory material into a coherent system of interrelated knowledge.
3. Alignment of all virtual laboratory practicals, delivery methods and evaluation, in accordance with the Polytechnics' Electrical/Electronics Engineering Syllabus, and in line with sector's move for implementation of CBT.
4. Continual process of review, identification and updating of lab content, practices, methods of evaluation , and other learning activities to suit the characteristics and educational needs of the individual student;
5. Investing in professional development for teaching staff, technicians and teaching assistants to support the new initiatives in virtual education.

www.ajaronline.com Vol.2, No.2 (Pages 40-50) ISSN 2408-7920 (October 2015)

This integrated deployment model provides a framework to focus on the objectives of training, reflecting real educational processes that must be carried out. This approach will help to minimize disruptions and encourage flexibility during deployment and integration.

5.1. Virtual Laboratory Realization and Evaluation

The development process follows the following steps:

- Realization of appropriate simulation platform in accordance with the criteria set out in section 2.2
- Decomposition of course into competency units and learning outcomes
- Creation of lab exercises and lab manuals
- Deployment and assessment

5.1.1 Realization of appropriate simulation platform

To fully utilize the virtual laboratory possibilities described in the previous sections, the software of a virtual laboratory system has to provide numerous features and functionality, depending on the requirements of the particular course. As established, this can be achieved by utilizing off-the-shelf software packages that emulate real lab processes in the form of virtual simulation environments. Clearly, it is unrealistic for a single software package to meet all the requirements of a multidiscipline programme involving many subjects. It is best to opt for a suite of software tools with complementary functionality that allows the full range of requirements to be met. In view of this, we have opted for a virtual simulation environments toolkit that comprises three “universal” simulation software packages: Matlab/Simulink, Multisim and Labview. Universal packages contain extensive library of components and instruments for the development of virtual interfaces of physical instruments and laboratory facilities. The choice of these three was informed by the range of complementary features and functionality that can be utilized to meet all the requirements of the programme. Used collectively, the three can synergize to greatly increases training opportunities. For example, Multisim can design and perform DC, AC and transient analysis of electronic circuits with device models. MATLAB can then carry out calculations of device parameters, curve fitting, numerical and statistical analysis, and perform two- and three-dimensional plots. Used in this way, an integrated approach provides a way to leverage the capabilities of different software packages for electrical system design and circuit analysis (Attia, 2010). The integrated simulation approach is important because of the multidisciplinary nature of the HND Electrical/Electronics Engineering programme. Virtual laboratory based on integration of universal software packages provides the opportunity to study a wide range of subject areas.
The main criteria for the development of the system are its flexibility and scalability that will allow us to include new courses and techniques as well as new methods of mathematical modeling of processes. The virtual laboratory simulation process is close to a real experiment (Fig. 1), allowing students to perform a sequence of operations such as assembly of the electrical circuits, connect measuring instruments, configure input actions of sources and generators. The display on the computer monitor familiar instruments, such as virtual oscilloscopes, ammeters, voltmeters, multimeters, function generator and tools for the study of digital electronics, makes the research process more natural and understandable.

AFRICAN JOURNAL OF APPLIED RESEARCH (AJAR)
www.ajaronline.com Vol.2, No.2 (Pages 40-50) ISSN 2408-7920 (October 2015)

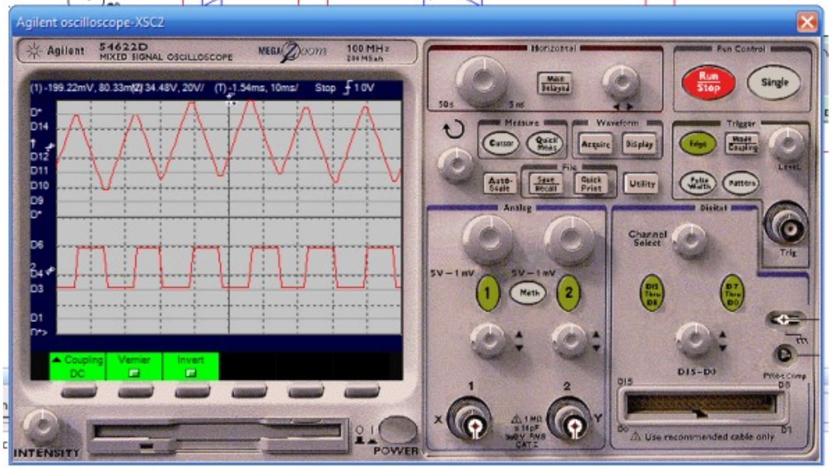

Fig. 1. User interface generated by Multisim, showing Agilent oscilloscope in action, during laboratory work to explore the characteristics of signal generators.

The virtual environment creates conditions for organizing and conducting experiments with a wide range of virtual electrical and electronic components, and the final results are the same as the processes in the real world. The computer models, with a wide range of adjustable parameters (Fig. 2) are the visual representation of numerical models that reflect the laws, theorems and principles of electrical engineering. In this way the student is able to set different performance characteristics, enabling and disabling the appropriate mechanisms to study objects under different conditions.

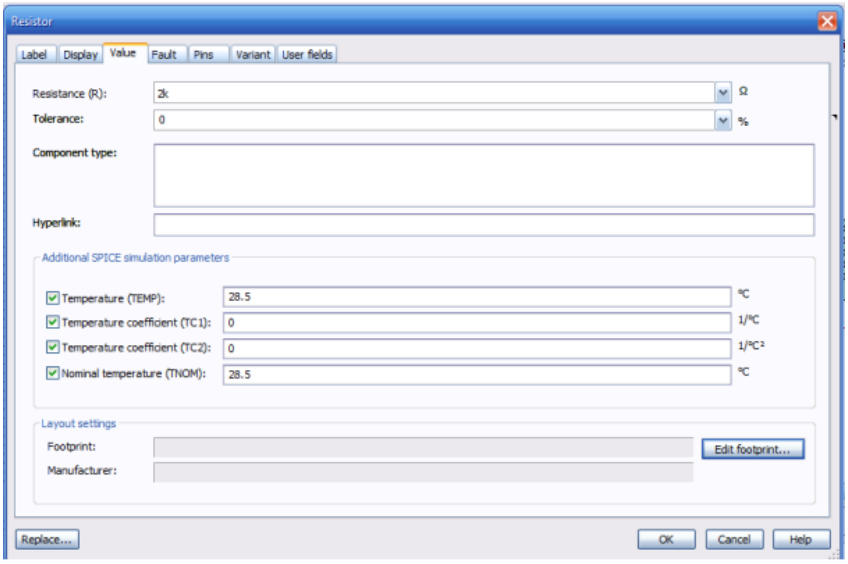

Fig. 2. Multitsim interface showing parameter editing window of a resistor.

5.2. Decomposition of lab into competency units and learning outcomes

Currently, most of the Electrical Engineering courses have a 3-hour laboratory component. Each laboratory practical involves a series of tasks directed towards teaching specific skills and key concepts, which the students complete during a three hour laboratory session. Analysis of all the labs reveal overlaps of learning outcomes, resulting in redundancy. In order to streamline the practical laboratory work, we undertook an audit of the course contents, laboratory aims, and expected learning outcomes for each lab. In order to practically implement and test the virtual laboratory system, each lab module was broken down into smaller competency units. For, example, the contents of the Electronics II lab as contained in the syllabus is summarized below:

- Basic op amp circuits;
- Signal generators;
- Wave shaping and signal conditioning circuits;

AFRICAN JOURNAL OF APPLIED RESEARCH (AJAR)
www.ajaronline.com Vol.2, No.2 (Pages 40-50) ISSN 2408-7920 (October 2015)

- Power Amplifiers;
- Active RC Filters.

For effective implementation of the virtual lab, these contents were decomposed into a sequence of units that provided coherent and rigorous content, aligned with the coarse objectives and learning outcomes, in CBT-style competencies as shown in table 1.

Table 1. Breakdown of laboratory content into competency units

Competency	**Key Learning Outcomes**	**Training Approach**
Identify and demonstrate the proper use measuring instruments	• Use digital multi-meters (DMM), oscilloscopes, function generators, and power supplies to build, analyze and trouble shoot electrical and electronic circuits. • Identify basic limitations of various measuring instruments such as multimeters, oscilloscopes, and wave analyzers.	Demonstration Simulation Discussions Lab Exercises
Read and interpret data sheet specifications for electronic components.	• Understand datasheet parameters • Select the integrated circuit (IC) appropriate to the defined specifications of a circuit.	Demonstration Simulation Discussions Lab Exercises
Applying Basic operational amplifier circuits, including active filters.	• Identify and define operating characteristics and applications of operational amplifiers circuits, including time and frequency responses. • Construct, analyze, and troubleshoot different kinds of and operational amplifier circuits. •	Demonstration Simulation Discussions Lab Exercises
Understand, construct and apply power amplifier circuits	• Understand the functions and classes of operation of power amplifiers, as well as their characteristics and applications. • Explain and demonstrate how to design power amplifiers with desired performance characteristics. • Construct power amps and analyse their behaviour using test instruments.	Demonstration Simulation Discussions Lab Exercises
Generate and condition various kinds of signals (square, sine, triangular and pulse waveforms) using oscillators and wave shaping circuits.	• Understand, apply, and evaluate the characteristics of signal generation circuits • Construct, analyze and troubleshoot sinusoidal and non-sinusoidal oscillators, negative and positive feedback circuits, phase shift circuits, phase-locked loop circuits, integrator, and differentiator circuits.	Demonstration Simulation Discussions Lab Exercises

Appropriate lab exercises were then created in accordance with the key learning outcomes above. The challenge was to design the virtual lab modules to meet the aims of the programme, whilst not exceeding the expected workload. To reduce student workload, the practical lab modules were streamlined to focus on the particular learning outcomes associated with the essential skills and knowledge addressed in each practical session. Also, an accompanying training manual that provides a step by step description of the laboratory work was also made. For lack of space in this article, the details of the lab exercises and the training manual are not given here.

5.3. Deployment and evaluation

The final step in the implementation process was the deployment and evaluation of the virtual laboratory system developed. For this purpose, specific competencies were chosen to examine the effect that the software has on student learning of practical engineering concepts. The pilot programme was based on the Electronics II course that was currently running at the time of this project. The choice of discipline and competencies for the current exercise took into account the limited time and resources available for developing process.

The preliminary assessment study shows that the use of virtual laboratory systems based on interactive computer simulators saves resources, time, and improves the student learning experience, which in turn leads to better education. It can be said that virtual lab technology is relevant now, and in the future, is very promising.

6. CONCLUSION

In this research paper we discussed issues of using interactive virtual laboratories to help students acquire new knowledge and practical skills in Electrical and Electronics Engineering. As established, the use of virtual laboratories is essential for providing students with hands-on exposure to a wide variety of engineering problems. Virtual laboratories can be used to illustrate key concepts that complement the theory in lectures or to develop basic practical skills in Electrical and Electronics Engineering, such as the use of equipment, the accurate recording of observations and analysis of experimental results.

Through the experience acquired in the process of developing and deploying the virtual laboratory system, we were able to identify and analyze important criteria for enhancing the effectiveness of virtual laboratory technology. Also, the analysis allowed us to identify a number of reasons for using the virtual laboratory in Electrical and electronics education training:

- The use of virtual lab enhances students' interest in the studied subjects.
- Improves the effectiveness of teaching in general, provides both group and individual approach to learning.
- The use of virtual laboratories contributes to the development of independence of students, instilling in them the ability to independently find solutions to engineering problems in the process of work, and to apply this knowledge in practice.
- Virtual experiments, being outside the existing technical constraints of real labs, provide the opportunity to plan and conduct a wide range of experiments to study the actual electrical systems and processes. The virtual simulation is, therefore, an ideal way of teaching students, as it eliminates virtually all restrictions on the components and instruments. This ultimately, expands the range and depth of the issues that can be study.
- Virtual laboratory practicals contribute to the formation of analytical skills, which in turn leads to the development of creativity and the ability of processing technical information. This is important for professional activities of engineers in the changing conditions of modern industry.

The newly created virtual laboratory provides a wide range of possibilities for the study of electrical and electronic circuits and systems that a real laboratory would require large financial costs because of the high cost of the necessary equipment. Implementation of this work is of practical importance, as the virtual laboratory system has been tested in practice and has proved its effectiveness. It has sufficient flexibility, and can be recommended for use in the Electrical/Electronics Engineering Department.
Finally, it should be noted that the ultimate aim of HND Electrical/Electronics Engineering is the acquisition of skills to handle and operate real objects and equipment. Therefore, it is best to adopt a combination of virtual and real experiments, in which a computer model of the process under study carries an auxiliary function of preparing the student for work with real objects, to speed up the processing of the data, drawing up reports on the work. In this regard, computer simulation of physical processes under study should be an essential component of the educational process, but it should not replace real laboratory practice. Rather, it should complement and deepen students' knowledge about the real equipment and processes and their physical properties.

Further research on the problem can be carried out in the following directions: assessment of the effectiveness of virtual laboratory training, and exploitation of virtual laboratory technology in distance learning,

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