Laboratory Instruction in Engineering Education*

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Laboratory instruction develops students' experimental skills, ability to work in teams and communicate effectively, learn from failure, and be responsible for their own results. There are three types of educational laboratories in engineering education. The oldest one is known as a hands-on laboratory with real instruments, the second is a simulated or virtual laboratory, while the last one is a remote or distributed learning laboratory. The effectiveness of any type of a laboratory depends upon the learning objectives that are associated with the laboratory. The laboratory environments may already involve a blend of hands-on, computer-assisted and simulated tools. Last year, a few educational laboratories were renovated and modernised at the authors' respective institutions. These activities were carried out in accordance with the laboratory development plans of the institutions and were based on the needs of study programmes. The modernised laboratory is a challenge to the academic staff to develop new and more effective laboratory instruction. In developing the laboratory, students' attitudes towards laboratory instruction were taken into consideration as well.

INTRODUCTION

I hear and I forget;
I see and I remember;
I do and I understand.

Chinese proverb

Engineering education is inconceivable without laboratory instruction. There are three types of educational laboratories in engineering education [1]. These can be listed as follows:

- The oldest one is known as hands-on laboratory with real instruments;
- A simulated or virtual laboratory;
- A remote or distributed learning laboratory.

It must be pointed out, that most laboratory environments may already involve a blend of hands-on, computer-assisted and simulated tools.

Educational goals for any type of laboratory are considered as follows:

- *Conceptual understanding*: the extent to which laboratory activities help students understand and solve problems related to key concepts taught in the classroom;
- *Design skills*: the extent to which laboratory activities increases students' abilities to solve open-ended problems through the design and construction of new artefacts or processes;
- *Social skills*: the extent to which students learn how to productively perform engineering-related activities in groups;
- *Professional skills*: the extent to which students become familiar with the technical skills they will be expected to have when practicing in the profession [1].

These goals are the most applicable for a hands-on laboratory, while design and social skills are not so specific for the remote and simulated laboratories.

The many aspects of the role of the teaching laboratory in engineering education were analysed by Feisel and Rosa in their paper published in the *Journal of Engineering Education* [2]. The authors presented a historical overview of engineering teaching laboratories, considered the application of computers in the laboratory to acquire data, analyse results, control and simulate experiments, and even use the Internet in order to provide students with remote access to instruments in a real laboratory. The authors also outlined the fundamental objectives of the engineering teaching laboratory. These objectives were formulated by some 50 distinguished engineering educators at the colloquy convened in San Diego, USA, in January 2002 and are cited below.

All the objectives start with the following: *By completing the laboratories in the engineering undergraduate curriculum, you will be able to...*

- *Objective 1: Instrumentation. Apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities.*
- *Objective 2: Models. Identify the strengths and limitations of theoretical models as predictors of real-world behaviours. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles.*
- *Objective 3: Experiment. Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterise an engineering material, component, or system.*
- *Objective 4: Data Analysis. Demonstrate the ability to collect, analyse, and interpret data, and to form and support conclusions. Make order of magnitude judgments and use measurement unit systems and conversions.*
- *Objective 5: Design. Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements.*
- *Objective 6: Learn from Failure. Identify*

unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions.
- *Objective 7: Creativity. Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving.*
- *Objective 8: Psychomotor. Demonstrate competence in selection, modification, and operation of appropriate engineering tools and resources.*
- *Objective 9: Safety. Identify health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly.*
- *Objective 10: Communication. Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.*
- *Objective 11: Teamwork. Work effectively in teams, including structure individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable.*
- *Objective 12: Ethics in the Laboratory. Behave with highest ethical standards, including reporting information objectively and interacting with integrity.*
- *Objective 13: Sensory Awareness. Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems.*

These objectives of laboratory instruction are in line with ideas presented by Wankat and Oreovicz in their book, *Teaching Engineering* [3].

Such a set of fundamental objectives can be useful for the guidance of engineering educators to develop and evaluate the effectiveness of laboratory experiences. At least that is the case at Kaunas University of Technology (KUT) and Kaunas Technical College (KTC), both based in Kaunas, Lithuania.

LABORATORY INSTRUCTION AT KAUNAS UNIVERSITY OF TECHNOLOGY

Circuit Theory is the basic course in electronics engineering education. The main aim of such a course is to provide knowledge of the methods of mathemati-

cal modelling and of solutions for electric circuits, as well as to develop abilities and skills for practical applications.

Within the Faculty of Telecommunications and Electronics at Kaunas University of Technology, the *Circuit Theory* course is run by the Department of Signal Processing and is traditionally a two-semester course. Every week, students have classes for lectures (three hours), tutorials (two hours) and laboratory (one hour). The duration of a laboratory experiment is four hours. Therefore, students attend the laboratory once a month, or four times in total per semester. Students usually work in groups of two or three, but separate reports have to be prepared and presented to the instructor for individual assessment.

Last year, the Department of Signal Processing received a grant for the purchase of teaching equipment for *Electric Circuits Laboratory*. There was a temptation to use virtual instruments instead of real ones because of the lower cost [4]. However, that idea was rejected since computer simulations today still cannot effectively replace hands-on experiments [2]. Thus, the grant was used for the purchase of instrumentation as listed below:

- GDM-8246 - dual display digital multimeter by Instek (ACV measuring frequency up to 100 kHz): 6 units;
- GDS-806C - digital storage oscilloscope by Instek (60 MHz bandwidth with colour display): 5 units;
- GOS620 - analogue oscilloscope by Instek (20 MHz): 3 units;
- GFG-8219 - function generator with built-in counter by Flite Electronics International (3 MHz, INT/EXT AM/FM modulation, and LIN/LOG sweep mode): 4 units;
- Flite's IDL-600 Analogue Lab (a unique platform on which analogue electronic circuits may be constructed with ease. This unit contains a built-in multi-rail DC power supply, analogue voltmeter and ammeter, and a function generator along with a large area of breadboard, switches, indicators, potentiometers and a loudspeaker): 7 units;
- PCS500 - 2-channel PC scope by Welleman (1000 MS/s with adapter): 2 units;
- PCG10A - PC function generator by Welleman (standard waveforms: sine, square and triangle, plus a library of predefined waveforms: noise, sweep): 2 units;
- Personal computer: 4 units.

The types and quantity of instruments selected had to meet the objectives of the laboratory, but were limited by funds available for the purchase. A compromise was found. Therefore, the *Electric Circuits Laboratory* was renovated and eight workplaces were equipped with new educational instruments for hands-on experiments. Besides that, four computers are available for the analysis and processing of acquired data, as well as for demonstrations and some simple simulations. For the needs of laboratory instruction, *LabVIEW* software and *MATLAB* and *Mathcad* packages are available as well. The modernisation of the *Electric Circuits* teaching laboratory was based not only on the KUT's educational experience, but on the expertise of colleagues as well.

Currently there are 10 experiments, modernised or new ones, prepared for laboratory instruction in the *Electric Circuits Laboratory* as follows:

1. Instrumentation and measurement – introduction;
2. Experiments with DC circuits;
3. Properties of circuit elements;
4. The resonance of a series RLC circuit;
5. The resonance of a parallel RLC circuit;
6. Two-port network frequency response;
7. Operational amplifier as a circuit element;
8. Differentiation and integration circuits;
9. Transient response in RLC circuit;
10. Experiments with modern filters.

The list of laboratory experiments is not fixed or closed. The modernised laboratory is a challenge to academic staff to develop new and more effective laboratory instruction. In this activity, a few doctoral students and some undergraduate students are also involved. Not all of these experiments are compulsory. For some clever students, a few – or even all – experiments can be replaced by an individual project that is carried out in the laboratory.

Survey of Students

In order to evaluate the effectiveness of laboratory instruction in the *Electric Circuits Laboratory*, a questionnaire was developed and distributed among second year students who had one semester of experience in the laboratory. The questionnaires were filled out in the classroom and were aimed at obtaining individual students' responses. Students were asked to rank lectures, tutorials, laboratories and individual study in a sequence of decreasing importance, and define by grades their own academic performance in learning *Circuit Theory*.

Table 1: *Circuit Theory*; results of the survey on students' opinions on lectures, tutorials, laboratories and individual study. The smallest number (*m*) in a row indicates what the surveyed students regarded as the most important.

	Lectures m±σ	Tutorials m±σ	Laboratory m±σ	Individual study m±σ
Attractiveness of classes	2.38±0.98	2.13±0.76	<u>1.75±0.95</u>	3.75±0.59
Attendance at classes	2.95±0.22	2.00±0.32	<u>1.05±0.22</u>	
The most valuable classes/activities	3.12±0.80	<u>1.57±0.67</u>	1.86±0.93	3.45±0.74
Most effective learning at	3.12±0.81	<u>1.34±0.53</u>	2.17±0.97	3.37±0.77
Acquired knowledge/skills (%) (in total 100%)	19%	<u>32%</u>	26%	23%
Circuit Theory: hours/per week Students' proposal: hours/per week	3 2.70±1.19	2 2.57±0.77	1 1.53±0.82	4 3.13±1.38

In all, 40 students took part in the survey. The results of the survey are presented in Tables 1 and 2. The numbers in these tables represent the mean *m* and the standard deviation σ of students' responses. The smallest number (*m*, underlined in the tables) in a row indicates what the surveyed students regarded as the most important. Table 3 presents the criterion-based grading system at the KUT and KTC.

The results of the survey shown in Table 1 demonstrate that attendance at the laboratory and attractiveness of the laboratory were rated the highest. This is understandable as the laboratory is equipped with modern instrumentation and laboratory classes provide students with first-hand experience in circuit theory concepts and with the opportunity to explore methods that are used by engineers in practice. Besides that,

Table 2: *Circuit Theory*; results of the survey on students' academic performance; the correlation coefficient of examination and laboratory assessment grades: *r*=0.49.

Student Performance at:	Average Grade as m±σ
Examination	6.83±1.52
Laboratory	<u>8.15±1.25</u>
Individual study/project	7.80±1.38

Table 3: The grading system at the KUT and KTC.

Pass/Fail	KUT/KTC Grade	ECTS Grade
Pass	10 (excellent)	A
	9 (very good)	B
	8 (good)	C
	7 (highly satisfactory)	D
	6 (satisfactory)	D
	5 (sufficient)	E
Fail	4 (insufficient)	FX
	3 (highly insufficient)	FX
	2 (poor)	F
	1 (very poor)	F

the laboratory is an ideal place for active learning [5]. Students learn in a real world environment, function as team members, discuss the planning of experiments, and share ideas about the analysis and interpretation of data.

It is no wonder that tutorials are considered by students as the most valuable learning environment and activity (Table 1). This is the case because the interaction between the instructor and student develops the student's ability to solve problems and perform home assignments. The majority of students are certain that tutorials are a major source of acquired knowledge (Table 1: 32%), with the laboratory classes behind. Presumably, this is also the case for *Circuit Theory*.

As shown in Table 2, students' academic performance is rather modest. This can be explained by the lack of motivation for students to study engineering [6]. But students' academic performance in the laboratory was better than their examination results, although the correlation of examination marks and laboratory assessment grades did not meet the researchers' expectations.

In the same way, the effectiveness of laboratory instruction was evaluated for the course *Signals and Systems*. The questionnaire was distributed among third year students who had one semester of experience in the *Signals and Systems Laboratory*. Nineteen students took part in the survey. The results of the survey are presented in Tables 4 and 5.

As shown in Table 4, attendance at the *Signals and Systems Laboratory* was rated the highest, but the laboratory was not so attractive for students compared to the *Electric Circuits Laboratory*. The situation is very much the same with students' academic performance in the laboratory (Table 5). Evidently, a laboratory with modern instrumentation is a good means to motivate students to study engineering.

Table 4: *Signals and Systems*; results of the survey: students' opinions on lectures, tutorials, laboratory and individual study.

	Lectures m±σ	Tutorials m±σ	Laboratory m±σ	Individual study m±σ
Attractiveness of classes	2.47±1.02	2.05±1.02	2.58±1.02	3.00±1.20
Attendance at classes	2.10±0.94	1.47±0.51	1.16±0.22	
The most valuable classes/activities	2.95±1.13	1.74±0.73	1.95±0.97	3.11±1.05
Most effective learning at	3.32±0.89	1.89±0.94	2.21±1.18	2.58±1.02
Acquired knowledge/skills (%) (in total 100%)	21%	32%	23%	25%
Circuit Theory: hours/per week	3	1	1	5
Students' proposal: hours/per week	2.55±0.93	2.18±0.87	2.00±1.34	2.73±1.01

Table 5: *Signals and Systems*; results of the survey on students' academic performance.

Student Performance at	Average Grade as m±σ
Examination	6.68±1.77
Laboratory	6.68±1.38
Individual study/project	8.00±1.80

LABORATORY INSTRUCTION AT KAUNAS TECHNICAL COLLEGE

The main objective of the KTC is to increase the effectiveness of engineering education by close cooperation with industry and a practical orientation of the professional courses on offer [7]. Industry needs graduates from colleges; therefore, colleges can expect some support from industry for the modernisation of laboratory equipment. These instruments for hands-on laboratories are not always up-to-date, but are still applicable for laboratory instruction.

Besides that, there are no problems for a college concerning the industrial placement of students. Industrial placement is a good opportunity for a student to work in a real environment with modern instruments. At least this is the case for Kaunas Technical College.

The effectiveness of laboratory instruction was evaluated for the course of *Analog Circuits*. The questionnaire was distributed among second year students after the completion of the course. In all, ten students took part in the survey. The results of the survey are presented in Tables 6 and 7.

Laboratory and tutorial classes are not separated at the College. The distribution of laboratory activities and tutorials depends upon the course type and features. For the *Analog Circuits* course, the majority of the time is devoted to laboratory instruction.

The results of the survey (Table 6) demonstrate that the attractiveness of the laboratory was rated the highest and the most effective learning took place in the laboratory classes. In addition to this, students' academic performance was the highest in the laboratory with respect to examination and individual study assessments, but the grade is unfortunately not high enough to satisfy an instructor.

The problem needs consideration, not only for colleges, but for universities as well. For the

Table 7: Results of the survey: student academic performance. KTC, 2nd year of study.

Student Performance at	Average Grade as m±σ
Examination	6.13±0.83
Laboratory	6.56±1.13
Individual study/project	6.33±1.00

Table 6: *Analog Circuits*. KTC, 2nd year of study.

	Lectures m±σ	Laboratory m±σ	Individual Study m±σ
Attractiveness of classes	2.00±0.87	1.63±0.92	2.44±0.53
Attendance at classes	1.44±0.53	1.56±0.53	
The most valuable classes/activities	1.67±0.71	1.78±0.83	2.56±0.73
Most effective learning at	1.89±0.78	1.44±0.73	2.67±0.50
Acquired knowledge/skills (%) (in total 100%)	39%	38%	23%
Analog Circuits: hours/per week	3	2	1

moment, we as engineering educators can only speculate on this.

CONCLUSIONS

The educational goals of laboratory instruction are fully implemented in various types of hands-on laboratories. Such an opinion still prevails among engineering educators.

The modernised educational laboratory for hands-on experiments provides a challenge to academic staff to develop new and more effective methods of laboratory instruction. The involvement of some clever students in these activities is on the rise. A hands-on laboratory with up-to-date instruments is a means to improve student's motivation to study engineering.

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BIOGRAPHIES

Romanas Vladas Krivickas is a professor of electronics of the Department of Signal Processing at Kaunas University of Technology, Kaunas, Lithuania. He graduated in radioelectronics from Kaunas Polytechnic Institute in 1961 and received his doctorate from Vilnius University in 1967. As a postgraduate fellow, he was at Tokyo University and the Polytechnic University in New York, USA. After graduation, he dedicated himself to an academic career. His research interests are in circuit theory, signals and systems, and digital signal processing. He is the author of two textbooks. Currently, he is in charge of curriculum development in the Faculty of Telecommunications and Electronics at Kaunas University of Technology.

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