International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:8, No:7, 2014

Active Learning in Computer Exercises on Electronics

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***Abstract*—**Modelling and simulation provide effective way to acquire engineering experience. An active approach to modelling and simulation proposed in the paper involves, beside the compulsory part directed by the traditional step-by-step instructions, the new optional part basing on the human's habits to design thus stimulating the efforts towards success in active learning. Computer exercises as a part of engineering curriculum incorporate a set of effective activities. In addition to the knowledge acquired in theoretical training, the described educational arrangement helps to develop problem solutions, computation skills, and experimentation performance along with enhancement of practical experience and qualification.

***Keywords*—**Modelling, simulation, engineering education, electronics, active learning.

I. Introduction

MODELLING and simulation help learners to understand the nature and a performance of the system they study. The act of simulating generally entails representing certain key characteristics or behaviours of a system, device, or process under the study. A proper arranged library of models serves as a suitable tool in learning and training. The models help to examine and to predict various situations occurring in an exploring system. Moreover, the models can be useful to plan the processes and to carry out different performance steps in laboratories. Future specialists may better answer their questions using computer models [1].

Over the last decades, simulation of electronic circuits became a major research topic. There has been much progress, but educational acceptance, particularly in cost sensitive areas, has not been high. Though the novel simulation systems were developed to overcome these limitations, they are generally restricted to modelling only those circuits that concern the particular application areas [2].

This paper displays a methodology that provides simulation benefits not only for narrow applications, but for the broad education sphere. Basing on the active learning approach, the students obtain their own responsibility for the circuit design and diagnosis outcomes. Doing these, they learn to become experts in the schemas and obtain a variety of experiences with most types of electronic devices. The learners identify the circuit functions and determine how they are supposed to perform. Thereafter, they search the signal input stimuli and collect the output data to compare them with the expected response defined in the textbooks and manuals. Beside the system design, students are responsible for appreciation of the diagnostic strategy. This requires them to analyse the circuits and their functional specifications. They should determine what faults and malfunctions were detected and at which tests and inputs the fault propagates [3].

There are no essential conditions appropriate to every electronic circuit or even to most schematics. The set of requirements that can arise is very diverse due to wide ranges of applications. Also, the relative weighting of importance of various features should fluctuate between particular applications. As electronic systems are used differently in the fields, the features of steady-state or dynamic accuracy, frequency and time responses, capability to withstand the surges, and electrical parameters required by a consumer are often themselves the decisive properties. The frequency range is the usual professional attribute for any kind of electronic circuits. Power regulation is another specialised feature. Also, the efficiency is the significant factor of a converter quality. Therefore, the list of the circuit properties is extremely rich and their simulation meets numerous problems in the contemporary learning technologies.

Multisim has been selected as the basic simulation tool for the bachelor's learning purpose. Its main modules anticipate the types of circuits [4]. Each of the components – an R-, L-, C-element, diode, transistor, thyristor, etc. – is inserted into the object and then the behaviours of the system are monitored by simulation that produces a description of how the overall system performs. Modelling in *Multisim* enables clear analysis of all electronic circuits, simple parameter variation in a broad range, and fine possibilities in result evaluation with virtual measurements. The libraries of *Miltisim* are well suited for electronic needs, providing different complexity levels of passive components, amplifiers, and switches, from ideal to precision dynamic models. Its built-in tools enable data processing, frequency analysis, and what is really important, interfacing with other simulation instruments, such as *Spice*, *Simulink*, and *LabView*.

The scope of the described experimental and computation works of the proposed learning system seems more holistic, complex, and different from those indicated in the closest existing systems, particularly [5]–[8]. It takes advantage of covering the whole spectrum of the learning problems in electronics. Moreover, the experiments and calculations are distributed between the applications and merge them with the common idea and the uniform methodological approach.

The goal of this paper is to present a new organisation of students' computer experimentation in the scope of active learning methodology. First, an active learning approach is shortly described. Then, the novel management of active exercise training is proposed. Next, some important details of

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the exercise implementation, followed by a number of specific resources for active experimentation are outlined. Finally, assessment throughout exercises is discussed.

II. Active Learning Methodology

As follows from our review [9], educational systems of many institutions are far from being abreast of the future industrial challenges in the field. Having realised this disparity between industrial requirements and knowledge imparted to the graduates, many universities involve direct, purposeful learning experiences. Concrete, reflective, experiential, and active learning are some terms used now to describe alternative constructivist pedagogical methods that fit the new learning styles. They are even more required in technical studies in which obviously concepts learned in class must be put into practice in different scenarios so that the students fully understand the fundamentals and acquire the necessary competencies to apply them in solving the real-world problems.

Traditional education covers those activities that people can learn from, but it does not generally boost the learning experience. From this viewpoint, active learning seems extremely prospective as it leads to better understanding and, eventually, to a lower burden. Many studies have investigated the positive outcomes and benefits from this approach [10].

An educational methodology of active learning popularised first in [11] focuses on the students' desire to learn i.e. that moves the responsibility of learning on learners by shifting from time-based to achievement-based education. A well-established precept of educational theory is that people are most strongly motivated to learn things they clearly perceive as a need to know. By providing learning through question formulation and finding appropriate resolutions and issues, a student-centred approach is realised at which the students take ownership of their learning. For that, the role of the academicians changes from the "oracle" dispensing knowledge to that of a "facilitator" guiding and supporting the students in their own learning.

The objectives of active learning are to expand significantly the educational opportunities for different groups of students, both the strong and the weak ones. Using this approach the students construct their own knowledge through learning skills, exploration, feedback evaluation, and reflection, based on their own experience [12]. Following the context of active learning, practice and exercises become the most important stages of engineering training whereas lecturing moves to the auxiliary role.

Different active learning techniques were implemented to obtain the best results in education [13]–[16]. They demonstrate that students who applied learning strategies had reached higher achievements than those who had not acquired these.

An active learning methodology was chosen at the Department of Electrical Engineering of Tallinn University of Technology as a prospective educational instrument. It was first developed for the course Power Electronics (AAV0020) [9], [17]. Next, the disciplines Electronics (AAR3320) and Advanced Course of Power Electronics (AAV0050) were incorporated into the research [18].

A five-year study was conducted from 2009 till 2013. The students of two specialities were enrolled in the three above disciplines, as shown in Fig. 1.

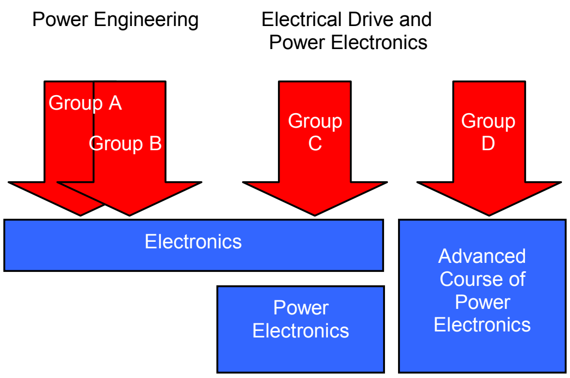

Fig. 1 Speciality-group-discipline diagram

Annually, two groups of 50 students studied Electronics offered within the bachelor's Power Engineering curriculum. One bachelor's student group of approximately 25 studied Electronics and Power Electronics in the specialisation of Electrical Drives and Power Electronics, and one master's group learned Advanced Course of Power Electronics. Totally, above 400 students participated in the case study.

The course syllabi follow quite a regular structure of engineering classes, such as two hours of lecturing and one hour of weekly exercises and laboratory work, plus the final exam at the end of the semester [19]. The total hours allotted to the particular courses are fixed by the curricula, therefore to introduce alternative learning the prescribed borders between lectures and other kinds of study could not be shifted to allow students to spend their learning time in an appropriate way.

III. Management of Active Computer Exercises

All exercise lessons incorporate five basic activities that promote active learning and give constructive feedback between the students and instructors involved (Fig. 2) [20]:

- off-site preparation
- in-class pre-work talk
- performance in a lesson
- in-class summing-up discussion
- off-site reporting

Again, in the compulsory part of those lessons traditional step-by-step instructions are used, resulting in the standard report with the circuit diagrams, calculations, experimental traces, measurement tables, and conclusions. In the new optional part of the exercises, a number of open problems may be framed by the teachers according to the topics in the syllabus. Based on long-term research, such an approach has been accepted, confirming that active learning introduces powerful dynamics for knowledge building and supports education at individual, group, and institutional levels [21].

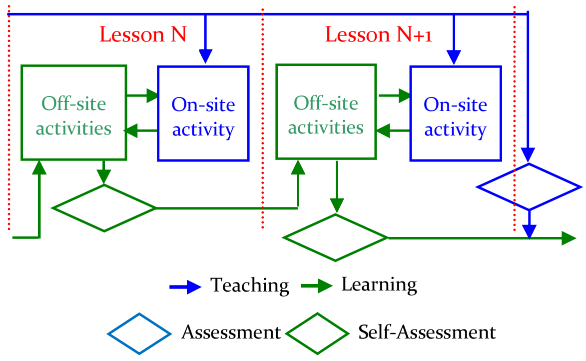

Fig. 2 Ways for traditional teaching (blue) and active learning (green)

To enhance appreciation by linking theory and practice, emphasis is on generating student's interest in the engineering methods and tools. As a rule, analytical problems are explained and collaboratively solved along with the compulsory part of the lessons before the personal problem statement. Every block of the lesson starts from the pre-lesson discussion combined with illustrations of application, such as observations and meaningful data as well as their general principles. Herein, the instructor encourages an active participation and facilitates understanding. The students are instructed in technical report preparation, student-to-student, and student-to-teacher collaboration as well as acquainted with the learning resources. This information is available also on the course Internet pages, where all other relevant materials are gradually posted along with the course progress.

TABLE I
CHANGES IN EXERCISE ARRANGEMENT

Indicator	Traditional teaching	Active learning
Electronics		
Number of lessons	5	7
− including the compulsory ones	5	5
− including the optional ones	0	2
Number of problems	5	32
− including the compulsory ones	5	5
− including the optional ones	0	27
− including circuits for students' self-calculation	0	27
Assessment scores	1	1 to 5
Power Electronics		
Number of lessons	5	5
− including the compulsory ones	5	5
− including the optional ones	0	0
Number of problems	5	27
− including the compulsory ones	5	5
− including the optional ones	0	22
− including circuits for students' self-calculation	0	22
Assessment scores	1	1 to 5

In addition to regular classes, self-directed learning issues were included into the exercise practice. To provide effective skill acquisition and to focus teaching and assessment on the needs and abilities of the learners, the existing exercise tasks were redesigned in the scope of the discussed bachelor courses, as given in Table I.

The full range of the exercises accessible by the students has been grouped into the thematic blocks shown in Table II.

TABLE II
EXERCISES IN ELECTRONICS AND POWER ELECTRONICS

#	Code	Thematic block
		Electronics
1	L	Linear circuits
2	F	Filters
3	D	Diode circuits
4	T	Transistor circuits
5	A	Op amps
6	M	Math converters
7	O	Oscillators
		Power Electronics
1	ACDC1	M1 rectifiers
2	ACDC2	M2 and B2 rectifiers
3	ACDC3	M3 and B6 rectifiers
4	AC	M1 and B2 AC converters
5	DC	M1 and B2 DC converters

Each block includes compulsory and optional works; therefore, every student must perform a minimum of five works in a discipline.

The self-prepared flash video "*Getting Started Multisim*" serves as an instrument to learn about using the *Multisim* toolkit in the study (Fig. 3). The video teaches the students how to develop, produce, and simulate power circuits, to detect and remove errors, and to prepare standard reports, thus providing training before the real design of electronic circuits. Here, the students learn to make schematic models in *Multisim*, select appropriate components, and combine them in the proper order. Later, the students launch the real simulation to understand electrical processes in electronic converters.

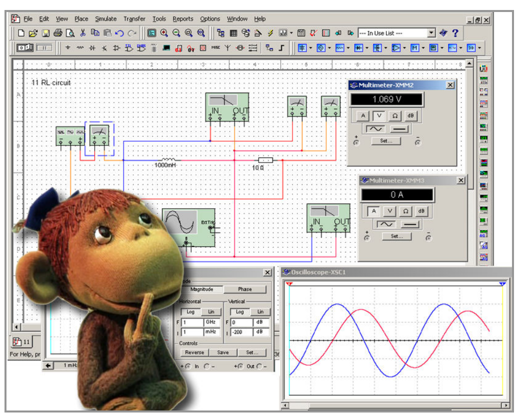

Fig 3 A frame of video about using *Multisim* in Electronics and Power Electronics

To provide successful home preparation for the classes, additional educational resources are recommended to the students similarly to those described in [22]. As a significant volume of the recommended resources is optional, they stimulate strong students' efforts in their success in active learning. At the same time, the weak students acquire mainly the mandatory information presented in the textbooks and manuals [23], [24].

IV. Exercise Implementation

Through the set of exercises discussed, the students practice the following skills:

- model development, commissioning, and improving in simulation
- inspection of the proper selection of electronic components
- examining the schematic correctness
- measurement of powers, voltages and currents as well as the frequency response and waveform analysis
- result explanation, reporting, and documentation

The proposed simulation instruments are suitable to compare the calculated and experimental data and to generate a report which typically includes

- experimental diagrams
- resulting and comparative data tables
- voltage and current traces
- dependency diagrams, if required
- conclusions with the explanation of the results obtained

The simulation components and instruments used in computer experiments involve the following models to provide effective design:

- power sources of different principles of operation, such as dc, ac, voltage-controlled, current-controlled, pulse, and clocking
- passive components: resistors and potentiometers, capacitors, inductors and variable inductors, switches and voltage-controlled switches
- diode circuits built on rectifier and Zener diodes, the full-wave bridge rectifiers and the silicon-controlled rectifiers
- transistors, particularly BJTs, FETs, and MOSFETs
- integral circuits, such as opamps, comparators, combinatory and sequential logic
- virtual measuring devices, including multimeters, wattmeters, voltmeters, and ammeters
- special instruments, such as virtual oscilloscopes, function generators, and Bode plotters

At the beginning of a lesson, students demonstrate to the teacher their preliminary knowledge level by answering a series of theoretical issues related to the practice implemented in the current session. To ensure a maximum profit from exercises it is essential that students undertake this assignment. The teacher highlights in situ the errors that students have done and they correct them herein.

After the implementation of each exercise, students should complete a draft report consisting of a summary of the major activities performed in each session and containing several basic questions related to the preliminary study and the work activities. In addition, the students add their reflections and questions being raised during the exercises. Off-site the students may develop the optional part of the work, prepare the final report, and upload it to the teacher's site. Part of the next session can be devoted for students' defence of their results using computer models and computations. Then, the teacher introduces the report corrected, whereas students can analyse their progress and mistakes made.

V. Assessment in Active Learning Context

It is a tradition that the grading and assessment schemes are largely prescribed by the host university. This evaluation division between the examinations and the practical credits is usually given in the curricula. The students are requested to take the theory exams, as these exams serve to qualify them for the next semester. The inability to assess higher order cognitive understanding and affective attributes via such assessment are often cited [25], [26]. Also, in the practice of estimation, the questions posed to students regarding important aspects of their work typically give a subjective and narrow mark. Such traditional "paper and pencil" assessment methods are usually criticised as too much oriented towards the exams, with very few other forms of evaluation and feedback being used [27]. When the sole purpose of an assessment is to measure the ability of students to respond to the questions asked in the form of credits and examinations, it does not answer whether the students can apply that knowledge and use it in the real world [28]. Here, the assessment is not considered as a part of the learning process, but rather something that takes place at a fixed time during the academic year.

Meanwhile, an assessment in the context of active learning is required to promote learning and ultimately students' progress and achievement and has a major influence on what learners learn, how effectively they learn and consequently on the quality of their learning. If assessment is considered as an integral part of learning, the students will be stimulated to adopt a deep learning approach, which is characterised by making connections and actively searching the meaning and appreciation of the given tasks. This is a prerequisite for the development of critical thinking [29] where all the participants of active learning employ assessment as a tool for the enhancement of education [30], [31].

One significant peculiarity of traditional engineering education is the difficulty in the practical application of the theoretical knowledge base. The knowledge transfer from the classroom to the new situations and contexts may not occur spontaneously. In most cases, deliberate teaching interventions are needed to increase the probability of occurrence of such transfer.

In terms of the approach offered, the evaluation strategy was redefined and reformulated for the goals of active learning to stimulate a learner by assessment and to receive currently the actual feedback. Now, active learning has become a way to overpass the barrier between the practical application and the theoretical knowledge [18].

Assessment during exercises invokes to evaluate:

- quality of the practice statement
- understanding of the learning objectives and the methodology used
- evaluation of the problem solutions under the practical headings
- practical experience and qualification obtained from simulation
- nature and appropriateness of student collaboration and group working potential

The evaluation currently applied consists in a continuous assessment throughout the course. The teacher-to-student feedback introduced by the formative assessment permits the imbalances that may occur during the course to be corrected and adaptation of teaching classes to each situation. For this reason, students and teachers have regular information during the course about the teaching/learning process. As the laboratory practice involves both the compulsory and the optional items, a learner may obtain additional scores if he/she implements the optional items. The scoring principle assumes obtaining one score for each solved problem.

The classroom talks and discussions are used regularly as an important tool of learning monitoring and students' assessment. To ensure students' readiness for a lesson, an instructor asks usually 10 to 20 questions before, during, or after the work. Students are asked to find answers to the preliminarily published questions. Correct answers increase the learner's personal rating. According to the simple scoring principle, a student wins scores for each correct answer.

Analyses of the in-class assessments have been resulted in the following:

- some students tend to approach the mandatory assessment level whereas most of them rush the optional level
- the reason of low scoring is the difficulty in the understanding of the optional level that requires additional time and knowledge
- the students of low motivation are more passive during the exercises, therefore special attention to that group is required
- there is an evident dependence between the exercise scores and the examination grades

The students' final examination grades in Electronics and Power Electronics are calculated as the averaged scores obtained from on-lecture quizzes, exercises, and labs. If a student's rating does not exceed '3', at the end of the semester he/she takes the examination the grade of which is based on the examination problem solutions and the actual practical achievements. These practical scores count towards 40 – 60 % of the student's total grade, with the remaining 40 – 60 % granted for the traditional theory assessment.

To support students' self-assessment in Electronics and Power Electronics, specific assessment modules were prepared as the combination of Web pages and Excel worksheets. As the learning process involves the compulsory tasks and the optional problems that add scores into the learner's rating, each object consists of three important parts: the results of the onsite lecture tests, laboratory assessment, and computer exercise assessment. During the semester, the students may follow online their current rating and their expected examination grade. Using these data, they obtain the tool to plan, adjust, and predict learning outcomes. Particularly, by solving additional tasks, they can improve their personal rating and their final grade.

VI. Conclusion

Traditional modelling and simulation practice provides ineffective techniques for the acquisition of experience and skills due to the surface-based approach to learning and evident learners' orientation to credits without opening their creative talents and engineering potential. In contrast, an active learning in computer exercises helps to develop such useful skills as the problem solution, effective calculations, experimentation performance, practical experience, and acquisition of qualification. Thanks to the new resources, an active approach became beneficial, leading to deep understanding and development of a conceptual knowledge base. It motivates introduction of international syllabi, proceeds the mutual curricula design in collaboration with foreign universities, ensures preparedness for instruction in English, attracts international students in the bachelor's and master's programmes, provides broader opportunities for students to take up studies at other recognised universities, and fosters flexible training techniques.

Acknowledgment

This research has been supported by Estonian Ministry of Education and Research (Project SF0140016s11) and the Program "Tiigriulikool" of Estonian Fund for Informational Technologies.

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