

THESIS ON INFORMATICS AND SYSTEM ENGINEERING C62

**The Interactive Learning Environment
For Mobile Laboratories**

MARTIN JAANUS

**TUT
PRESS**

TALLINN UNIVERSITY OF TECHNOLOGY
Faculty of Information Technology
Department of Computer Control

**Dissertation was accepted for the defence of the degree of Doctor of
Philosophy in Control and System Engineering on April 4, 2011**

Supervisor:

Prof. Vello Kukk, Department of Computer Control, Faculty of Information
Technology, Tallinn University of Technology

Opponents:

Dr. Toomas Plank, University of Tartu, Estonia

Prof. Peeter Normak, Tallinn University, Estonia

Prof. Peteris Misans, Riga Technical University, Latvia

Defence of the thesis: June 10, 2011

Declaration:

Hereby I declare that this doctoral thesis, my original investigation and
achievement, submitted for the doctoral degree at Tallinn University of
Technology has not been submitted for any academic degree.

/Martin Jaanus/



Copyright: Martin Jaanus, 2011
ISSN 1406 -4731
ISBN 978-9949-23-084-6 (publication)
ISBN 978-9949-23-085-3 (PDF)

INFORMAATIKA JA SÜSTEEMITEHNIKA C62

Interaktiivne õpikeskkond mobiilsetele laboritele

MARTIN JAANUS



Abstract

The aim of this thesis is the development of an interactive learning environment for mobile laboratories. The development supports the learner's individuality and manages the learning process through lab tasks and other active learning forms (self-tests) complementarily. The thesis concentrates mainly on developing proper tools for laboratory activities.

The specific aims of the thesis were formulated as follows.

1. Developing, implementing and testing the interactive learning environment in a real learning process, collecting and analysing the answers, and generating hints both to a student and a teacher.

2. Developing laboratory assignments with a customised content, integrating them into the learning process and using them for knowledge control.

3. Developing the mobile laboratory equipment supporting the personal learning process.

The thesis concentrates on the development of an interactive learning environment for mobile laboratories carried out from 2006 to 2010 in the Department of Computer Control of the Faculty of Information Technology at Tallinn University of Technology.

A fully web-based learning environment had existed already at the time of the commencement of the present development, but it was based on a traditional organisation of the practical work. The experience had shown that this part of the learning process did not qualify as expected and was ineffective despite the students had identified practical assignments as the most useful component of the study.

To achieve the specific aims, the following components of the learning environment were developed and the following activities were undertaken.

1. The HomeLabKit was developed. It is a small mobile box containing all necessary laboratory equipment to perform the practical work. The HomeLabKit is designed to be simple and as inexpensive as possible. The notable advantages of the HomeLabKit could be considered its mobility, flexibility and durability, also its low cost. Besides, it enables personalizing learning. Laboratory experiments can be performed at the time and place appropriate for a student. In addition to the HomeLabKit, only a computer, the Internet and a power network (if necessary) are required.

2. Flexible, changeable contents of the laboratories with the allocation of competencies and credit units on different parts of the syllabus of the course were created. Competence-based simple lab experiments were introduced and conducted instead of traditional laboratory tests. Compared with the traditional form of labs, those changes reduced remarkably the amount of information

acquired, and at the same time, enabled the significant increase in the total number of individual laboratory tasks.

3. The operational error analysis based on the student's attempts, particularly the unsuccessful ones, allows to adapt to the student's individuality and to manage acquiring knowledge and skills. The student's memory model was introduced and tested. The model simulates the behaviour of human memory to forget with time and highlights possible shortcomings in the students' acquired knowledge. It should be noted that the processing of the reactions of a student is instant and serves as a measuring instrument in the learning feedback system.

4. A new method for compiling lab works, processing of results and extracting of competences has been developed.

5. The environment was analysed and the statements characterizing the students' behaviour were formulated. These results can be used in the future development of implementing and complementing the student's behaviour model.

The contribution of the author of the study lies in the components described in Chapters 3, 4 and 5, namely, in developing the HomeLabKit, simple lab experiments and the analysis of results, also in introducing the student's memory model.

The specific aims were achieved. The developed environment was tested in a real learning process and the students' behaviour was observed for 4 years. The results of the analysis of students' behaviour and the answers of assignments were taken into account in the organisation of the learning process. This analysis was supported by the data logs collected for 10 years.

The author of the dissertation determined also the main aims for the future. Firstly, to introduce the next, third generation of the HomeLabKit. Secondly, to develop the competence-based interactive learning environment. Thirdly, the results of the current thesis are the great source for implementing the overall student's behaviour model. The author has already started with realising the aforelisted aims.

Kokkuvõte

Käesoleva töö eesmärgiks on mobiilsete laboratoorsete tööde teostamist võimaldava interaktiivse õpikeskkonna arendamine, mis toetab õppija individuaalsust ning juhib õppetööd laborite ja teiste aktiivsete õppevormide (enesetestid) koostöö kaudu. Antud töö keskendub laboratoorsetele töödele vajalike töövahendite arendamisele.

Tööle püstitatud alaeesmärgid olid järgmised.

1. Interaktiivse õpikeskkonna arendamine, rakendamine ja testimine tegelikus õppeprotsessis, tulemuste automaatne analüüs ning vihjete genereerimine nii õppijale kui ka õppejõule.
2. Kohandatava sisuga laborikatsete arendamine, nende integreerimine õppeprotsessi, samuti laborikatsete kasutamine teadmiste kontrollis.
3. Individuaalset õppeprotsessi toetavate mobiilsete laboriseadmete komplektide arendamine.

Käesolev töö keskendub mobiilsete laboratoorsete tööde teostamist võimaldava interaktiivse õpikeskkonna arendamisele Tallinna Tehnikaülikooli infotehnoloogia teaduskonna automaatikainstituudi siduteooria ja -disaini õppetoolis aastatel 2006 kuni 2010.

Töö alustamise hetkeks oli loodud täielikult veebipõhine õpikeskkond, kuid selles kasutati traditsioonilist soorituspõhist praktikumide korraldust. Saadud kogemus näitas, et just see osa õppeprotsessis ei vastanud eesmärgipärasusele ega efektiivsusnõudeile, kuigi üliõpilased hindasid õppetöös kõige kasulikumaks komponendiks just praktikume.

Töös on eesmärkide saavutamiseks loodud järgmised põhikomponendid ning läbi viidud järgmised tegevused.

1. HomeLabKit'i loomine. HomeLabKit on kaasaskantav laborikohver, mis sisaldab kõiki konkreetsetes õppeaines olevate praktiliste tööde sooritamiseks vajalikke seadmeid. HomeLabKit on projekteeritud maksimaalsest lihtsusest ja odavusest lähtudes. Laborikohvri suurimateks eelisteks võib pidada mobiilsust, kohandatavust ja vastupidavust, samuti selle odavust. Lisaks võimaldab see õppevahendeid personaliseerida. Õppija võib sooritada laborikatseid individuaalselt valitud ajal ja kohas. Peale HomeLabKit'i on nõutav vaid arvuti, internet ja vajaduse korral elektrivõrk.
2. Paindlike, muutuva sisuga laboratoorsete tööde loomine koos ainepunktide ja kompetentside omastamisega õppeaine programmi erinevatele osadele. Traditsiooniliste laborikatsete asemel on kasutusele võetud kompetentsipõhised lihtsad katsed. Võrreldes traditsioonilise laborivormiga, on oluliselt vähendatud

korraga omandatava info hulka, võimaldades samal ajal tunduvalt suurendada üksikute laborikatsete koguarvu.

3. Õppija (eelkõige ebaõnnestunud) soorituste alusel toimub pidev vigade analüüs, mis võimaldab adapteeruda õppija individuaalsusele ning juhtida teadmiste ja oskuste omandamist. Kasutusele on võetud tudengi mälumudel. Mälumudel modelleerib inimese unustamist ja näitab õppijatele nende võimalikke ununevaid teadmisi.

4. Loodud on uus meetod laboritööde koostamiseks, tulemuste töötlemiseks ning kompetentside ekstraheerimiseks.

5. Analüüsitud on arendatud õpikeskkonna praktilist kasutamist ning lisatud õppijate käitumist iseloomustavad väited, mis võimaldavad oma suhtelise muutumatuse tõttu kasutada ja täiendada õppija mudelit ka edaspidises arendustöös.

Töö autori panuseks on peatükkides 3, 4 ja 5 kirjeldatud komponentide loomine ja arendamine, täpsemalt HomeLabKit'i, lihtsate laborikatsete ja tulemuste analüüsi loomine ja arendamine ning tudengi mälumudeli tutvustamine.

Eelnimetatud alaeesmärgid on saavutatud. Arendatud keskkonda on katsetatud realses õppetöös ning üliõpilaste käitumist on jälgitud nelja aasta vältel. Õppijate käitumise ja ülesannete vastuste analüüsimise tulemusi on võetud arvesse õppetöö korralduses. Teostatud analüüsi toetavad ka kümne aasta jooksul kogutud andmed.

Töö autor on kindlaks määranud peamised tulevikueesmärgid: uue, kolmanda põlvkonna HomeLabKit'i tutvustamine, kompetentsipõhise interaktiivse õpikeskkonna edasiarendamine, tudengi käitumismudeli rakendamise täiendamine. Töö autor on juba alustanud loetletud eesmärkide täideviimisega.

Acknowledgements

I would like to begin by expressing my sincere gratitude to my parents and grandparents, especially to my grandfather who fostered in me a deep interest in electronics and technology, always inspiring and impressing me by his encyclopedic erudition and unreserved support in my undertakings.

My supervisor, prof. Vello Kukk has become an example of a professor for me towards which I am trying to tend. He introduced me to the topics of circuit theory and then provided me with necessary freedom for fulfillment of developmental interests.

I would also like to express warm thanks to my colleagues from the Department of Computer Control and also to friends from the Department of Electronics who, without any doubt, gave me good advice and access to the equipment that I did not have.

Abbreviations

Abbreviations used in the thesis.

AC – Alternating Current
CMR – Common Mode Rejection Ratio
CT – Circuit Theory
DC – Direct Current
HLK – HomeLabKit
LED – Light-Emitting Diode
opamp – Operational Amplifier
OS – Operating Systems
PC – Personal Computer
TUT – Tallinn University of Technology
USB – Universal Serial Bus

Abbreviations used in names of assignments.

ACC – AC calculations
ACT – AC transfer
DCC – DC calculations
DCT – DC transfer
FRES – Frequency response
KCL – Kirchhoff's current law
KVL – Kirchhoff's voltage law
M – measurements
OL – Ohm's law
PH – Phasors
RES – Resonance
RMS – root mean square
TP – Twoports

Contents

Abstract	5
Kokkuvõte	7
Acknowledgements	9
Abbreviations	10
List of figures	13
1. Introduction	15
1.1 Lab assignments	16
1.2 Motivation	17
1.3 History of development	18
2. Main features of isc.dcc.ttu.ee learning environment.....	24
2.1 Overview	24
2.2 Field of assignments	25
2.3 Ability levels	27
2.4 State machine	27
2.5 Theoretical tests.....	29
2.6 Lab assignments	30
2.7 Class tests (micro exams).....	31
2.8 Final mark	32
3. Developing of HomeLabKit.....	34
3.1 History of HomeLabKit.....	34
3.2 Basic concept of designing HomeLabKit.....	36
3.3 Solutions for lab devices	37
3.3.1 DC power supply.....	37
3.3.2 Three-phase AC supply	39
3.3.3 AC generator and scope	42
3.3.4 Operational amplifier	44
3.3.5 Twopole, twoport, fourpole and transformer	46
3.3.6 Two-terminal components.....	47
3.3.7 Types and content of HomeLabKits.....	47
3.4 HomeLabKit usage and statistics	52
4. Creation of lab assignments	56
4.1 Historical notes.....	56
4.2 Concept of elementary lab experiments	58
4.3 Lab assignments	59
4.4 Structure of lab assignments.....	59
4.5 Processing lab results	62
4.6 Students' behaviour	68
4.7 Teachers' role.....	73

5. Student's memory model.....	75
5.1 Motivation	75
5.2 Memory models.....	76
5.3 First model.....	76
5.4 Results and analysis (2006 vs. 2007)	77
6. Conclusions	87
6.1 Overview	87
6.2 Contributions	88
6.3 Future goals	89
7. References	90
8. Publications	96
8.1 Publications related to this thesis	96
8.2 Other publications related to scientific research	97
9. Appendices	98
9.1 Examples of lab processing scripts	98
9.1.1 Resistance measurement.....	98
9.1.2 Kirchhoff's current law	99
9.1.3 AC measurements.....	103
9.2 List of lab competences for the subject "Circuits, systems, signals"	105
ELULOOKIRJELDUS.....	108
CURRICULUM VITAE	110

List of figures

Figure 1 Learning Court	20
Figure 2 Hierarchical structure of assignments (in 2009)	21
Figure 3 Learning as a closed loop: the feedback is given by a human	25
Figure 4 Learning as a closed loop: learning is managed by a computer	25
Figure 5 Assignment diagram (the student's view).....	26
Figure 6 Structure of the assignment field	26
Figure 7 Student's state machine.....	28
Figure 8 Self test processing algorithm	29
Figure 9 Lab assignment processing algorithm	30
Figure 10 Lab assignment processing algorithm	32
Figure 11 First generation of the HomeLabKit	35
Figure 12 DC power source.....	38
Figure 13 Structure schematic of the DC source.....	39
Figure 14 Three-phase AC source.....	40
Figure 15 Three-stage sine waveform	40
Figure 16 Spectrum of the output of the AC source (negative values indicate the phase shift 180°)	41
Figure 17 Structure schematic of the 3-phase AC source	41
Figure 18 AC generator and scope	42
Figure 19 Structure schematics of the AC source	43
Figure 20 Screenshot of the AC source software	44
Figure 21 Opamp device	45
Figure 22 Structure schematic of the opamp.....	45
Figure 23 Course specific devices.....	46
Figure 24 Resistors, capacitors and inductors	47
Figure 25 HomeLabKits – the external view	48
Figure 26 HomeLabKit – opened.....	49
Figure 27 Screenshot of a lab kitting web page	51
Figure 28 Lab attempts using the HomeLabKit	52
Figure 29 Amount of home activity in fall semester 2009	54
Figure 30 Lending time	54
Figure 31 Lab assignments until 2006	56
Figure 32 Previous complex lab assignments (in 2004).....	57
Figure 33 Structure of the present learning environment	58
Figure 34 Hierarchy of lab assignments.....	60
Figure 35 Current measurement	61
Figure 36 Resonance measurements	61
Figure 37 Correct and incorrect lab results	63

Figure 38 Circuit to be composed in the AC lab	64
Figure 39 Schematics to be composed in the twoport measurements	65
Figure 40 Incorrect answers in the twoport assignments	66
Figure 41 Lab attempts at university	66
Figure 42 Lab attempts at home	67
Figure 43 Number of attempts by the final mark	67
Figure 44 Percentage of unsuccessful attempts by the final mark	68
Figure 45 Lab attempts (in a day)	69
Figure 46 Homework submission before the deadline (Kukk's Curve 2003).....	70
Figure 47 Amount of assignments performed during the fall semester 2009.....	70
Figure 48 Overall use of the learning environment in 2009.....	71
Figure 49 Number of performed assignments per student	72
Figure 50 Number of lab experiments performed by one student (in the fall semester 2009). The dots show the days when attempts were made.	72
Figure 51 Teacher's activity log in the fall semester 2009.....	74
Figure 52 Assignment TNC will fall to the lower threshold	78
Figure 53 Prediction curve shown to the students.....	78
Figure 54 Number of assignments activated at higher levels.....	79
Figure 55 Number of attempts per ability levels	80
Figure 56 Session results, forgetting process and items for a new time constant ...	81
Figure 57 Lab experiments at different levels.....	82
Figure 58 Class test experiments at different ability levels.....	83
Figure 59 Number of actions active in different time periods.....	84
Figure 60 History of one assignment in 2006	85
Figure 61 History of one assignment in 2007	85
Figure 62 Screenshot of a resistance measurement task	98
Figure 63 Screenshot of the task for the application of Kirchhoff's current law ...	100
Figure 64 Assignment of AC measurements.....	103

1. Introduction

This thesis is dedicated to the world at the time of the latest learning technology – e-learning – and its inseparable part in technical teaching, namely web-based lab activities. The rise of information technology has influenced mankind profoundly. Today, computers are put to use in all fields of life – from entertainment to scientific calculations. After all, the computer has become the main communication tool.

Although e-learning is ubiquitous nowadays, it lacks the precise definition. One among many would be as follows: e-learning is the learning method, which is supported by modern technology [1]. E-learning can be informally defined as a software solution for educational purposes, which is based on theoretical postulates, trends in cognitive science, artificial intelligence, and pedagogy [1]. E-learning in its infancy meant the use of electronic media such as audio and video recordings, and later the materials in shared disks.

Education innovations such as e-learning systems make strong connections between theory and real-life [3]. Through the years, for ways to facilitate learning, e-learning is one of the most effective methods [4]. Then, interactive video-conferencing was developed. With regard to the Internet (and in particular the data transfer speed), the next development step was to place the materials on the Internet. All of this enables to conduct the study outside the educational establishment. Next, some modifications of e-learning have appeared – m-learning (i.e. learning using mobile devices) and i-learning (i.e. learning using portable audio players like the iPod) [5], [6].

The main principle in developing an interactive learning environment is that the learning process is handled as a technological feedback system based on management objectives, an adequate measuring and the appropriate use of control algorithms.

Today, the aforementioned e-learning could be considered as the most suitable and flexible learning system for the reason that students often study alongside working. Therefore, the courses including laboratory tests and a knowledge test can be conducted via the Internet. Experience has shown that students accept Internet-based learning with enthusiasm. Students vary in knowledge, skills and abilities. Also, they have different amount of time for learning. Besides, having the opportunity of using modern technology encourages the students to experiment.

1.1 Lab assignments

The lab activities have been given a central and distinctive role in technical education. Hands-on activities and demonstrations have been developed and documented for teaching students. Researchers have also proposed methods for creating hands-on learning that help shift the focus from the teacher to the student [11]. Some laboratories use technology and hands-on manipulative tools to discover concepts and theorems [12]. Laboratory instruction helps students develop their experimental skills and ability to work in teams, learn to communicate effectively, learn from failure, and be responsible for their own results [13]. Based on the studies, it can be found that students learn and retain much more of what they experience directly or practice doing, as opposed to what they only hear or see [15]. Also, labs can develop skills and attitudes such as creativity, autonomy and self-learning to solve real-life problems.

Nowadays, when technology has advanced greatly and supports learning efficiently, labs need to be interactive. Interactivity means that, like in other learning activities, immediate feedback should be provided to the student. Besides, in order to achieve well-functioning interactive lab assignments, their content must be adaptive dynamically according to the student's answers. However, applying conventional technology inhibits achieving the aim.

The mobile set of lab devices – the HomeLabKit (also *HLK*) – was developed in order to increase the amount of practical work significantly. Personalized learning allows presenting separate tasks at a detailed level in a user-specific way, and that can be repeated until success is achieved. Besides, the number and complexity of the tasks can be varied. In addition, the developed mobile set makes the learning process attractive. In the developed learning environment students submit their answers and are provided immediate feedback on their performance. Also, in case of an incorrect answer, they are directed to appropriate study materials. As an example, it could be compared to the way children play computer and Internet-based games. They learn very fast, make decisions and draw conclusions of the rules during the game. The used method is called cognitive – trying until success is achieved [12], [17], [18], [19].

The other reason for creating interactive lab assignments is the following. Lectures are usually supported by laboratories, but they are carried out only at certain times and on limited bases. Besides, they cannot be repeated. Typically, courses end with an examination, which generally shows only a skill of reflecting knowledge [16].

In the current study, in order to improve personal learning, all classroom lectures were cancelled. Instead, the lectures were recorded and made available over the Internet. Also, the number of consultations was increased because every student is different and requires therefore a different

approach to knowledge.

By the time when the author of the thesis started developing mobile labs, many e-learning environments had been developed (e.g., WebCT, Moodle). These all had one common aspect, namely they were only teaching tools for organising and archiving the results. However, they did not support creating adaptive web-based practical assignments.

1.2 Motivation

There are several motivations for this work. The most essential motivation is to create better learning conditions for students. Experience has shown that using e-technology improves students' motivation.

When this study was started, the situation was characterised by the following aspects.

1. The learning activities are becoming the part of the modern information and communication technology (e-learning) [20]. In other words, the majority of assignments became place and time independent. Yet it did not affect the practical part of the course, namely, even if the reports were in e-mode, labs were still traditional, students depended from school premises and had to a lesser or larger extent rigid timetable.

2. Laboratory space and time constraints will lead to negative effects, the most important is the volume of work restrictions – for few students the scheduled time may be sufficient, however, many of them need a lot of more time [21].

3. The laboratory equipment is relatively expensive and obtaining it in larger quantities is unfeasible. Since the laboratory equipment is developed only for specific functions, it can be considerably cheaper and thus, the quantity of the equipment can be increased.

4. If labs are taking place in the premises of the school, it is difficult to repeat the measurements, which is essential in the case the work-related calculations show that some measurements should be repeated or added.

5. Particularly cumbersome and ineffective were the laboratories for distance learning and distributed learning of the colleges, because the solutions were not effective.

6. Modern-day students and companies are dissatisfied with the contemporary curriculum. Also, learning methods are archaic [22]. They prefer to use modern methods and 'learning by doing' [23], [24].

7. Many laboratory courses have become an iterative process in which students only seek to meet requirements and pass the course [25].

These assumptions were in effect in 2005 when the HLK was introduced and the first steps were taken in order to change the learning process. The results of

this work are reflected from the actual instruction and experience. Intentionally, there were no experiments conducted.

Consequently, the following tasks were set to the learning environment.

1. Developing flexible labs with a changeable content accompanying certain credit units given to different parts of the course.
2. Automating the analysis of results and generating helpful hints to a student and to a teacher.
3. Creating the knowledge base using both tests and lab experiments in the web-based environment.

1.3 History of development

In the following, the solutions and decisions that have been made in order to reach to the present e-learning environment are described. During the development process, a number of seemingly promising solutions were terminated after their inconsistency was proved in the reality. Sometimes, the outcome was surprising, especially when it concerned commonly accepted opinion.

The development of the e-learning environment in the Department of Computer Control of the Faculty of Information Technology at TUT was started at the end of the 1990s by introducing simple web-based services which made available the course materials (lecture slides), set up some automatically processed tests, communication tools (questions and answers), the registration for lab events, lecture plans, and provided personal view of final marks. However, lab reports and homework were still presented as paper documents and consequently, processed by a teacher with a remarkable delay. The delays appeared to be cumbersome, extending even to weeks, particularly because of a tremendous number of reports. Apparently, the manual processing of the reports tended to be rather superficial [26].

However, despite of limited facilities, the students' reaction should be considered positive. For example, the survey conducted in 2001 among 134 students participating in the Introductory Course in Electrical and Computer Engineering ("Circuit Theory", hereinafter *CT*) in the Department of Computer Control at TUT showed the following. About 56% of students used mainly their own computer to present reports. The majority (95%) preferred to present their reports via the Internet. It was found that three-fourth of respondents (75%) preferred to get learning materials from the Internet, whereas 25% preferred learning materials on paper. As for exercising, a significant percentage of students (84%) preferred the Internet, 12% exercised on paper and only 4% used a textbook. More than a half of respondents (60%) downloaded the lecture notes from the web, 22% preferred to have the lecture notes on paper from the beginning of the course, and 18% preferred to receive the lecture notes before a

lecture. Approximately one third (33%) of the students wrote their lab reports in a lab on the computer after the measurements had been completed; another third of the respondents (31%) compiled the lab reports partly in a lab and partly at home; a minority of students (8%) submitted their lab reports on paper. As for getting support for solving problems, explanations provided by a teacher were on the first place. The most critical remark was made about server faults.

In 2002, the uploading of homework into the database was introduced. The aforementioned supplementary feature simplified processing homework. However, delays were not reduced significantly. In the CT, the number of tests was increased from 6 to 9, tasks were generated stochastically, but because of a relatively limited number of the difficulty levels (10), the average number of attempts per test and student was about 10, and that was definitely insufficient for persistent learning.

In 2003, the experimental work was moved to the web in the whole extent. It included an electronic form for the assumed preparation for a lab conducted at home, and presumed working in a lab with a computer only and uploading all results during the work. Certain verification was added to the lab software. Thus, the most common errors were marked by the red colour suggesting the student to verify his work. The teacher processed the results using the same template.

In this version of labs, there is seen explicitly how students used instant feedback (the coloured results of measurements or calculations) – to get the result accepted they started to ‘tune’ data. Using several colours indicating different levels of accuracy helped the students. A more sophisticated ‘calculation’ was based on client-side scripts that were available to a user. The students opened the source code of the web page and then, after extracting the proper parts from it, they could easily get correct results. That has been the most interesting in-site operation provided by students. Before that time, file sharing (reports of homework, labs etc.) was the most widespread activity in the learning processes involving computers. During the following years, the students created a number of special websites and Excel files that helped the students to get correct results. For some reason, analysing the client-side code by the students had dropped to almost zero, probably because the learning software did not include the relevant code at the client side.

During 2003, two series of lectures (both “Circuit Theory” and “Operating Systems”) were recorded as audio files. However, their usage was near zero and therefore, the links to those files were eliminated and no more audio files were produced.

A significant step was made in 2003. Students had asked several years to have a tool for exercising. Manual dissemination and what is more important, checking students’ lab reports was inefficient because of a large number of students. Using tests for that purpose was not appropriate because those were created for an examination and therefore, no comments were issued. Therefore,

the Learning Court (Figure 1) was designed to be open for all students independently of their current assignment activities. Tasks were collected into modules representing separate topics, e.g. Ohm's law, units (DC and AC separately), series connection, parallel connection etc. The modules had a hierarchical structure where the higher module opened only when the lower one(s) had reached a certain level. The total number of the modules that were initiated was 40, but only 268 tasks were implemented. There were 6 difficulty levels a limited number of which caused constant complaints from the students as same tasks appeared. In 2004, the number of active modules was reduced to 33, the number of tasks and levels were increased to 332 and 8 respectively. A remarkable increase was noticed in the usage of the Learning Court. In 2003 (the first year of implementation), this number was 6196, then, in 2004, the number reached 36,347. This confirmed that the right tool had been found and further development was needed.

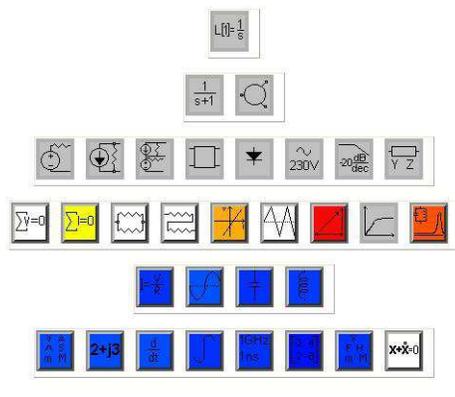


Figure 1 Learning Court

The year 2005 marks some decisive actions. More attention was concentrated on the success of the Learning Court, the problems with the classical organisation of labs and the inefficient control of learning process, and the following steps were made.

First, the course was represented as a set of assignments ordered in the same way as the tasks on the Learning Court. The sets of assignments were accompanied by a small amount of credit units so that the sum of them was equal to the credit units needed to pass the course. The number of the levels assigned to the assignments was 13 (from 0 to 12) with level 5 as minimum to be considered as the positive outcome of a particular assignment. In the course CT, there were 12 assignments as tests, 7 labs and 4 class works that covered several test assignments each. So, credit units accompanied with assignments were in the range 0.1...0.25, making together 3.5 cu (Figure 2).

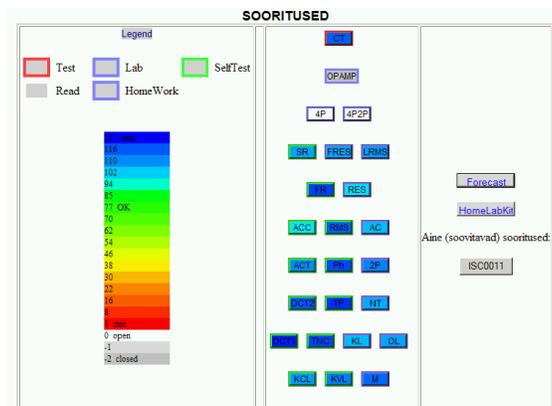


Figure 2 Hierarchical structure of assignments (in 2009)

Second, labs were still the same as previously and organised in the same way, but a new significant project was introduced in fall semester 2005. In that year, a project was initiated to design HomeLabKits – the boxes consisting of all the components needed to perform labs at home. The first experience with the kits was so successful that after a couple of months it was decided that all labs conducted both at university and at home would be based only on those kits.

Third, presenting regular lectures was finished and the recorded videos accompanied by lecture slides were made available (on a DVD and via the Internet). Links to them were organised at the slide level.

Fourth, the deadlines for presenting laboratory experiments were abandoned and the limits for repeating actions were removed. This step was carefully considered after analysing the results. The fact that all students' activities had been logged from 2000 simplified the decision-making process. Until 2005, tests were also open for certain time but they had to be reopened repeatedly to meet students' requests. Contrary to the common understanding about deadlines, the most remarkable effect was that the first students passed the course in 2.5 months instead of the standard 4.5 months. As for late students, no changes could be noted – about 15% remained late.

In 2006, the development became the main part of the PhD study.

In 2007, several more significant improvements were introduced. First, the student's forgetting model was introduced. Second, the number of tasks in the Learning Court was increased tremendously, to about 15,000. Third, labs were totally reorganised. The last action was supported by another project in which the second generation of HomeLabKits was designed. In this project, several institutions took part and totally 200 kits were designed. Those two actions were supported by increasing the number of knowledge levels to 128. That was absolutely needed for the implementation of the actions taken.

Learning without deadlines was a success, but showed clearly that the

assignment-based learning system had certain drawbacks: there was no mechanism to support remembering the studied items. Once a topic was passed, the student did not return to it. Also, the learning environment did not provide any guidance indicating students what they had probably forgotten during the time. It caused surprises, especially when some final examinations were provided. This was the main reason to insert the forgetting model into the learning environment as a tool that should control learning instead of strict ordering.

The forgetting model implemented was relatively simple: after every action taken by a student, not only a new level of knowledge (difficulty, ability) was calculated, but at the same time, the decay time constant was upgraded as well the floor, i.e. the level that was assumed to be the long-term memory level. This model needed more levels than used before; perhaps even real numbers could have been used, but it was decided that 128 levels would be sufficient to avoid the discretization effects as it happened in the common assessment practice where only 5 or 6 grades were used. Such a low number of state values would not have enabled the effective implementation of the feedback control.

Since the assignments were kept as in the previous models, a student could see the last levels of all assignments and the prediction for the next 16 weeks on a separate sheet. The length of the course, namely 16 weeks, was approximately equal to the length of a semester and was meant for calculating the final mark, i.e. the levels were taken into account 16 weeks later. It follows that learning in a short time before the final exam (the formal deadline) becomes impossible or inefficient, as the learning results will form in four months.

In 2007, it was also decided to transform labs to the format that had proved its efficiency in learning theoretical material. It should be mentioned that 'theoretical' here included besides theoretical claims or theorems also the tasks to be solved in tests and exercises. This decision together with the necessity to increase the number of tasks in any module, namely an assignment determined the thorough development work. At that time, it was obvious that creating numerous different experiments was impossible due to the limited resources of the HLK and complicated processing of measurement results. From the other side, the content of the HomeLabKit supported increasing the variety of assignments.

The most important feature of the assignments created in the developed learning environment is that the reaction is immediate and a student sees the change of the level immediately after sending the answer. The selection of tasks is automated and controlled by a feedback loop including the evaluation of the result, changing the state and selecting a new task from the set assigned to the new state.

Before the changes in 2007, class works (micro-exams) included theoretical tasks only. Then, experiments were included and the time slot was increased from 20 minutes to 40 minutes. The total number of assignments (modules) was

21 (12 tests and 9 experiments). The average number of test tasks and experiments per one class work was almost equal. This confirmed that experiments were more difficult for the students. It was also seen from the average results, which were 1.68 for experiments and 1.90 for tests (in the scale 0.0...3.0).

After the major changes in 2007, more tasks and some changes in control have been implemented. One of those was the confirmation of the final mark by a student himself/herself. When the student has reached the required levels in all assignments (has been evaluated taking into account 16 weeks into the future), the mark is being proposed and the student has two options: to confirm it or to continue to reach a higher mark.

By 2010, it became clear that enough experience had been collected to start creating more sophisticated processing of action results. This work was based on log files from which it was possible to extract knowledge elements. The main goal was to find out where and why students made mistakes or what had been misunderstood. The analysis performed by spring 2010 showed that in average about 4 instances of elements could be extracted from any task. The principal difference from the previous processing was that instead of evaluating the specific assignment from which the task had been presented, from every answer implication for several elements were made. It had been a problem in all previous solutions, because some summative grading was needed to be produced.

The contribution of the author of the study lies in the components described in Chapters 3, 4 and 5, namely, in developing the HLK, simple lab experiments and the analysis of results, also in introducing the student's memory model.

2. Main features of isc.dcc.ttu.ee learning environment

The chapter is divided into 8 sections. First, an overview of the developed learning environment is given. Then, the main component of the learning environment, namely the field of assignments, is studied. Next, the ability levels and the principles of the the state machine are introduced in separate sections. One of the sections is devoted to web-based theoretical tests. In addition, lab assignments performed by students using the HomeLabKit are treated. Finally, the main principles of class tests and a final mark are explained.

2.1 Overview

The learning environment implemented in the Department of Computer Control of the Faculty of Information Technology at TUT has been developed during 8 years as a fully web-based one. That means the absence of any paper documents and keeping logs of all activities performed by students. In the following, a short description of the developed learning environment – isc.dcc.ttu.ee – is given (ISC is the abbreviation of the chair, DCC stands for the department and TTU abbreviates the university where this work has been conducted).

The main difference of the developed learning environment from conventional e-learning environments is that conventional learning environments are mostly the tools for organising and storing results. The results are assessed by a human who gives often a subjective result (Figure 3). The main difference of the developed learning environment is that learning is controlled by a computer. Assessing and processing of results are fully automated (Figure 4).

To use the learning environment isc.dcc.ttu.ee, a student must be registered in it. The learning environment can also be used in a guest mode, but most of features are disabled. The main features of the interactive learning environment for a student are the following;

1. communication between a student and a teacher,
2. the field of learning materials,
3. the field of assignments,
4. the learning court,
5. the registration to a class activity (a lab or a class test),
6. the HomeLabKit lending management.

All assignments that had to be performed in fixed places (a computer class or a lab room) have based on pre-registration. The courses have a hierarchical assignment structure where a student has to start from lower level assignments and move up after successful completing. The structure represents either logical order or replaces time schedule. Every assignment is accompanied by credit units (0.1...0.4).

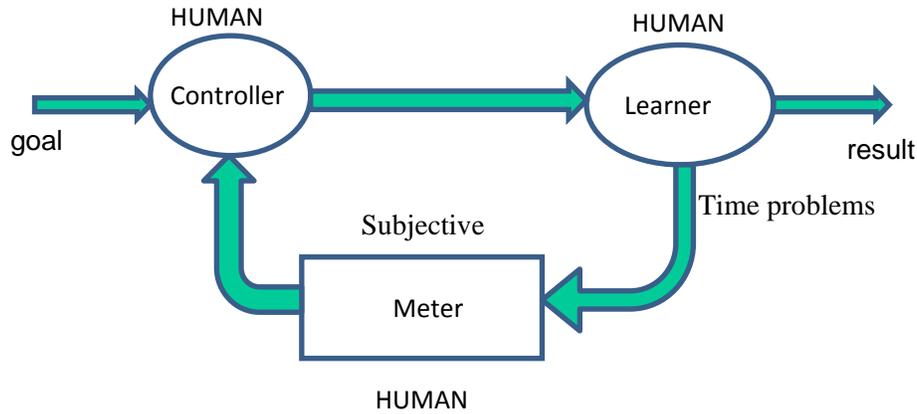


Figure 3 Learning as a closed loop: the feedback is given by a human

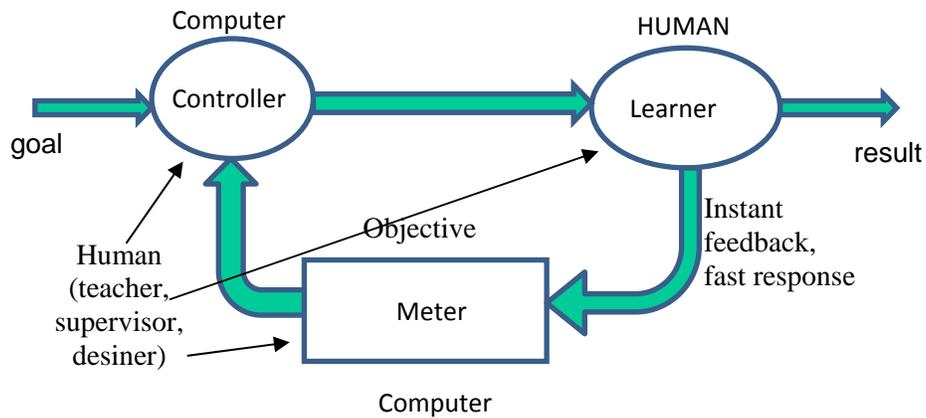


Figure 4 Learning as a closed loop: learning is managed by a computer

2.2 Field of assignments

The field of assignments is the main component of the learning environment (Figure 5). All active learning based events are organized there. The field includes all types of assignments and the information on a student's current

status. All prerequisites are also displayed. In the field, a learner selects an assignment by clicking to the icon (Figure 6).

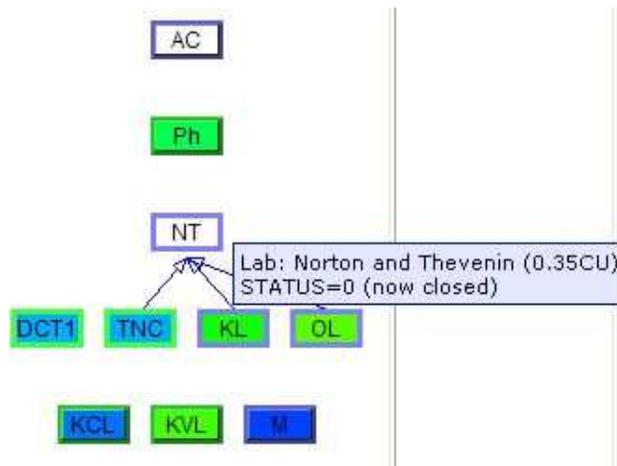


Figure 5 Assignment diagram (the student's view)

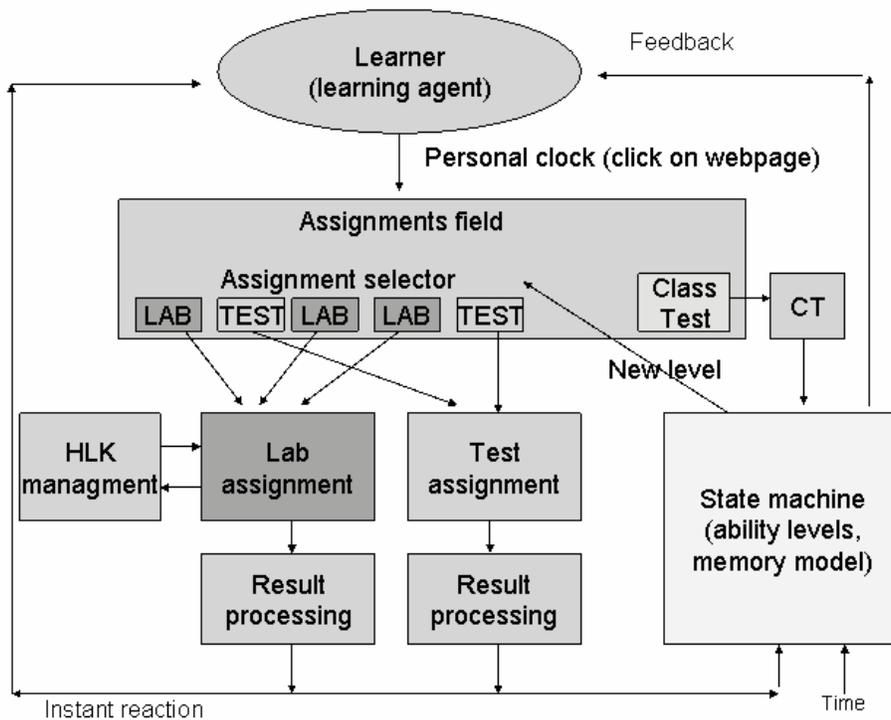


Figure 6 Structure of the assignment field

All types of assignments have different handling routines. The assignments used in the ISC learning environment are of the following types:

- self-tests,
- lab experiments,
- class tests ('micro exams').

2.3 Ability levels

The types of assignments are managed by the control engine as follows. A student has in every assignment (topic) its current state (the level of ability) described by a value from 1 to 127. Value 0 is used as the initial value showing that an assignment is open. The negative value shows that it is closed. The assignment opens when all prerequisites have reached the threshold value that has now set to common value 77 for all assignments. To change the levels' state, the state machine is used.

2.4 State machine

A state change is the result of an action taken by a student – that means solving a problem given by the environment and determined by the current state. Depending on the correctness of the answer, a new state is calculated using transition equations. The correctness is evaluated either by binary values, a finite number of values between wrong and correct, or real values between the same limits. Transition functions used are shown in Figure 7. In this figure, the input (the current state) is located horizontally and the output (the new state) vertically. The lower curve corresponds to a wrong answer, the upper to an absolutely correct one, the line in the middle marks 'neutral', and the bold line indicates the threshold level. Neutral means, for example, in a multiple choice test 2 correct out of 4 (50%). As seen from the graph, the steady-state value for that answer is 38 – far from the threshold. The threshold level is 62.5% from maximum.

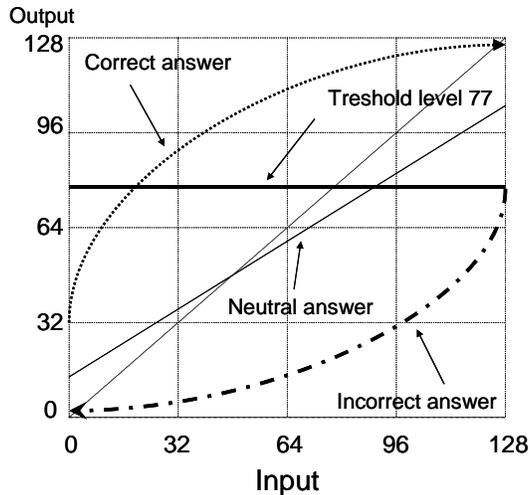


Figure 7 Student's state machine

One of important characteristics of the transition function is the number of correct answers needed to achieve a certain state. For the maximum level 127 this is 7 attempts. To reach the threshold level, 3 correct answers are enough, but this has not been observed probably because such student continued to reach higher levels.

To reduce influence of stochastic probes that was observed in previous years, some timing constraints were applied. Depending on the time used to give the answer, the change of the state is dumped. For example, in self-tests if an answer is given in less than 5 seconds, the calculated change in state is multiplied by 0.2. In addition, certain answer configurations may cause further reduction. For example, analysis showed that in multiple selection tests, the answer mask 0000 (nothing clicked) was a typical 'probing' selection and the reduction coefficient 0.5 was applied in that case. Applying the timing factor did not reduce the number of attempts made by a student, but reduced the oscillations of a state. However, the analysis shows that the general timing model is too simple and appropriate constants must be applied for every particular task or at least for groups of tasks. This is not simple as every topic in self-tests consists of about 2500 tasks.

In addition, the state machine uses the forgetting model. Using the forgetting model means that the level decreases in time without any action by a student. That may mean deactivation of dependable assignments. Previous experience has shown that such degradation is important to achieve learning goals. The forgetting model is described in Chapter 5.

2.5 Theoretical tests

Students have to pass web-based tests that are prerequisites to labs. Tests are not authenticated and therefore they are used as a training facility (class tests are based on the same tasks). The total number of tests is 12; the acceptance uses the following criteria: to reach to the threshold level (77). All the tests use choice answers and have the following structure. A prototype situation is given (for example, a circuit diagram with component values) and the student is asked to find from other 4 cases those where some characteristic (for example, the current value) is the same. So, in every task the number of correct ticks is from 0 to 4. Evaluation is dynamic: the student has the current state evaluated by levels 0...127 (initial is 0). After receiving a result (0..4) from a student, the server calculates a new state using a special transition table. The minimum number of attempts to reach the maximum level is 5.

Those tests are not intended to train the application of formulae or standard calculation scenarios. In most cases, the selection of the correct answer can be started from the exclusion of wrong ones by a simple calculation or observation. To find matches, one should compare some simple values or structures; usually a full solution is not needed. So, the main purpose of those tests is to train different simple evaluation and recognition methods, the most valuable for an engineer.

All tests, except the lower ones, have prerequisites. Before proceeding that is checked (the ability level of prerequisite tests must be at least 77 (Figure 8)). If the level is lower, the student is guided to prerequisites.

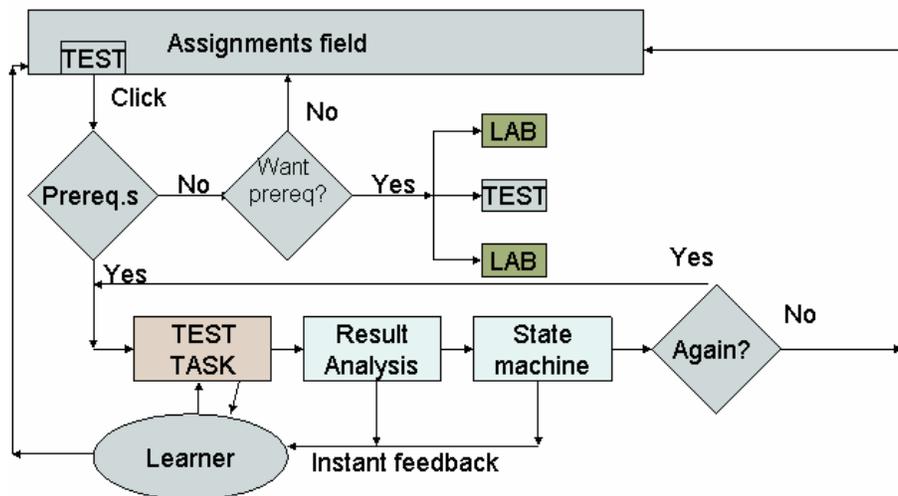


Figure 8 Self test processing algorithm

Every test is based on a set of about 1500–3000 different tasks. The number of structurally different pictures in a test is about 40–50, but the automatic reconfiguration produces 4–30 times more schematic: circuit diagrams and graphs are generated at a client’s side (JavaScript).

2.6 Lab assignments

The major handling difference between a lab and test assignments is time and workplace dependence (when lab assignments take place at university) and the HomeLabKit management (Figure 9). In addition to the check of prerequisites, there is also the check of the correct workplace and the time slot. If lab assignments are performed at home, a student must register for a home lab (HomeLabKit lending). The idea of lab assignments and the result analysis are described in Chapter 4.

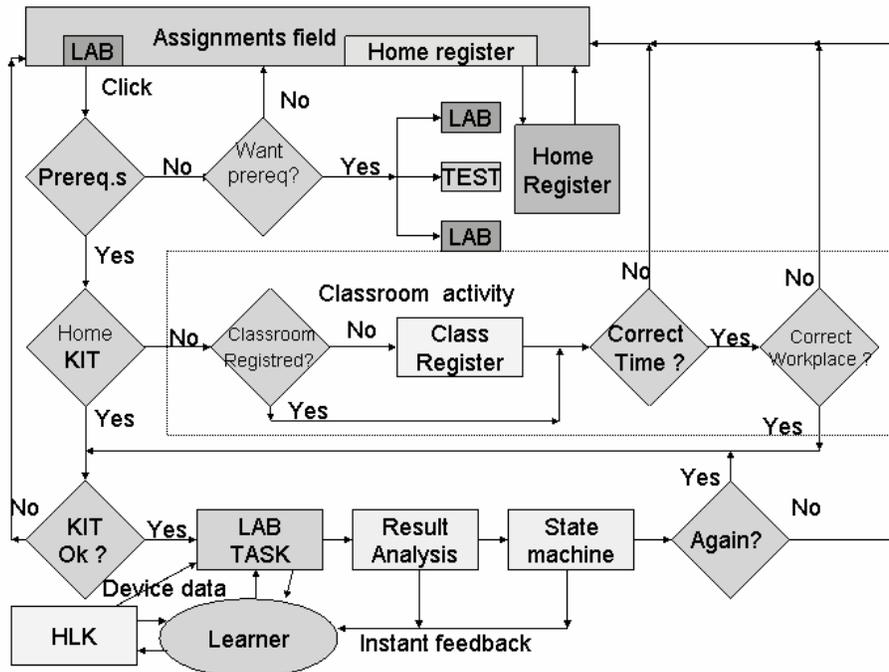


Figure 9 Lab assignment processing algorithm

2.7 Class tests (micro exams)

In class tests, the same tasks as in tests are to be solved, but a numerical answer must be given. Also, the lab assignments are included into a class test. A class test has some prerequisites: the level of 5 assignments (a lab or a test) should be higher than the threshold level (77) including forgetting. The structure of processing a class test is similar to a lab assignment (Figure 10). The main difference is the task selector. The goal of the task selector is to give to a student the appropriate task. In general, the task is the assignment (a lab or a test) which ability level is the lowest. In addition, the ability level of the assignment itself should be higher than the threshold. After processing the assignment's results, a new level of the current class test assignment is calculated. Moreover, the class test affects the level and the forgetting constant of a similar lab or test assignment. It is one of the motivating tools against cheating.

The class test is passed when the ability level in each class test topic is higher than the threshold level. In case of an unsuccessful result, the class test must be repeated. In case of a successful result, the final mark is calculated and the student is asked to continue or quit. In case of continuing, the final mark depending on the answer can rise or fall.

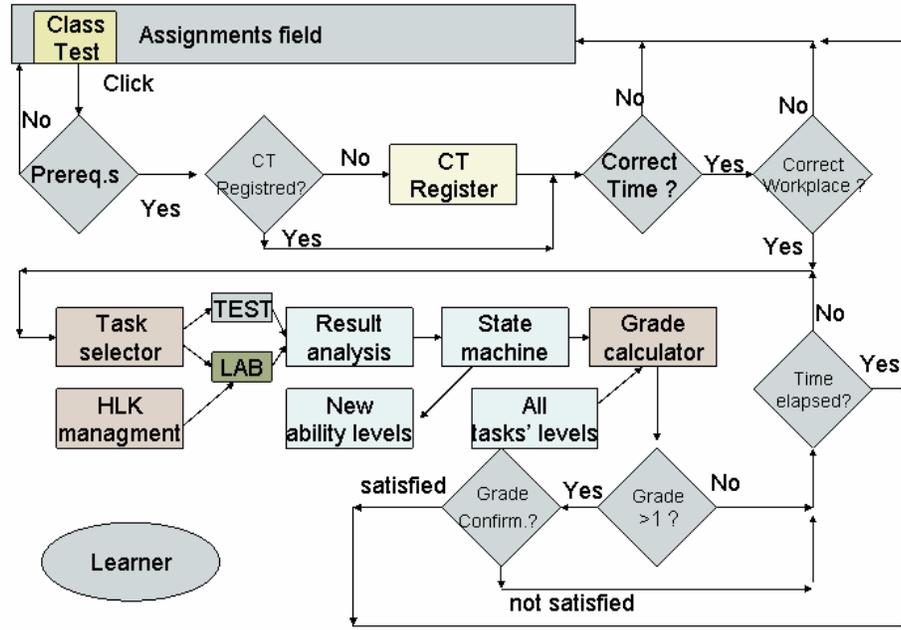


Figure 10 Lab assignment processing algorithm

2.8 Final mark

If all ability levels are higher than the threshold, the final mark is calculated. The levels of all assignments are included to the calculation. All assignment levels AL (in 16 weeks) and the class work states WL must be ≥ 77 . Credit units per assignment are in range 0.1...0.4 (a unit equal to 40 hours). The sum of credit units must be equal (or more) to the official number assigned to a particular course in the curriculum. The weights for regular assignments are $w_a=0.3 - 0.4$ depending on the course, and the corresponding weights for class tests are $w_w=1-w_a$. The average value L of products $AL \cdot w_a$ and $WL \cdot w_w$ is calculated (1).

$$L_{avg} = \frac{\sum w_{a_n} * AL_n + \sum w_{w_n} * WL_n}{\sum w_{a_n} + \sum w_{w_n}} \quad (1)$$

The final mark is detected using the function (mapping) described in Table 1.

Table 1 The mark mapping table

Level range	77-83	84-93	94-104	105-114	115-127
Mark	1	2	3	4	5

3. Developing of HomeLabKit

This chapter concentrates on the mobile laboratory equipment named the HomeLabKit. The first section gives an overview of the history of the HomeLabKit. The basic concept of designing the HomeLabKit is presented in section 3.2. Finally, the usage of the HomeLabKit and the related statistics are provided.

3.1 History of HomeLabKit

Although a web-based course was conducted in the Department of Computer Control at TUT for a long time, the web-based course did not support implementing laboratory works. An important difference between the traditional laboratories was that the registration and the reports were web-based (essentially just filled web forms). Checking a student's results was still a craft, but there were the learning court and automated self-tests already.

In 2004, Kuressaare College of TUT began to teach electronics. Some courses were taught in the way the lectures were held in different subjects on different days and in one subject at a time throughout the day. To make laboratory assignments, students were required to arrive to Tallinn, or the equipment itself had to be moved to Kuressaare. That is why the idea of the HomeLabKit was born. At that time more attention was paid to distant and virtual labs [28], [30] which were obviously less expensive and may promise higher level of cooperation [31], [32]. Also, at that time no reference to similar solutions could have been found. All solutions found were based on distant and remote labs (e.g. [27]), but nowadays a similar idea of the HomeLabKit is used in several universities [42], [40].

There were two choices to be had: a distant lab and a mobile lab. Web-based laboratories have been used for a long time. Unfortunately, they are either simulations [28] or distant labs (the equipment has the computer interface [29]). In both methods, a major drawback is the lost of reality. Computer-based communication cannot effectively replace hands-on experiments [33], however it can effectively complement them [34]. Also, computers can effectively be used to acquire measurement data [35]. From the beginning, the aim was to offer a mobile laboratory set. The use of the kit should be simple, flexible,

reliable and mechanically durable. It must also be relatively inexpensive because it can only fulfill its purpose if there are several kits for specific purposes available.

When composing the HomeLabKit there was a choice to use the industrial components or to design devices ourselves. At first glance, it seemed that the use of the industrial equipment appears to be a more suitable solution. Investigating the matter, it became clear that the equipment, which is consistent with the courses conducted at TUT, is not produced or the price of its components (e.g. a signal generator, an oscilloscope, a power supply) is high. Moreover, there is too much functionality in the industrial equipment. It was therefore necessary to design all of the devices. Only multimeters are industrial devices.

Two home lab projects were carried out: the first generation of the laboratory kits was for the testing purpose (Figure 11) and the second project focused on designing main components [36]. Both projects were co-financed from the foundations of the European Union. Besides, one of the aims of the second project was to involve other departments and universities from Estonia. Both projects were successful: the HomeLabKit projects supported developing similar kits in other Estonian universities.



Figure 11 First generation of the HomeLabKit

3.2 Basic concept of designing HomeLabKit

Understanding of the circuit theory concepts and linking them with practical tasks might cause problems [37]. Therefore, all devices must be as simple as possible and their characteristics clearly visible. The purpose of a device is only to have essential features. For example, an opamp model was designed because the real opamp had too good parameters. Therefore, they require relatively expensive measuring equipment [38], [39].

But the implemented model has all real characteristics of a real, decreasing the cut-off frequency to few kHzs. In this case, all the parameters can be measured using inexpensive measuring devices. Moreover, the purpose of a test is intended only to show the features of the device. Therefore, there was set a list of parameters, which were required from all devices. They are shown in Table 2. Those parameters have been chosen because of electrical safety, low consuming power and computer compatibility. In addition, devices must be as small as possible. Properly designed laboratory devices in the field of analogue electronics promote the acquisition of the necessary knowledge of the subject studied [41].

Table 2 Required parameters of devices

Voltages	Below 30 V
Currents	Below 500 mA
Power (V*A)	Below 1W
Frequency	Below 20 kHz
Computer interface	USB 1.1

Using those parameters, the following devices were designed: a DC power supply, a 3-phase AC power supply, a signal generator with a scope, an operational amplifier (opamp), an autonomous twopole, a resistive twoport, a transformer and separate components: a resistor, a capacitor, an inductor, a variable resistor, a nonlinear resistor.

To learn essential electronics there is no need of expensive equipment [43]. Industrially produced devices are only multimetres and connection wires; all other equipment has been designed in TUT by the author of this dissertation and under his guidance. The reason why not to use industrial equipment is simple – there are no devices with appropriate parameters or their price is too high.

The appearance of devices has remained the same since 2000 [44], [45]. They were designed by the author of this dissertation in his bachelor's thesis. As the design and mechanical parameters of the devices were excellent, they have been taken as a model. All devices have been placed into a 35x90x110 mm [46] plastic box, which has necessary connection terminals.

All devices are indexed. Parameters are measured and they are entered into a

database. All parameters were chosen so that each device is unique. Thus, it is made sure that a student is using right devices.

3.3 Solutions for lab devices

Next, special attention is paid to a DC power supply, three-phase AC supply, AC generator and scope in three separate sections. Also, an operational amplifier, twopole, twoport, fourpole, transformer and two-terminal components are given as the solutions for lab devices. In addition, different types of HomeLabKits are introduced and their content is listed and commented.

3.3.1 DC power supply

A DC power source must have two modes: a voltage source – an output voltage is constant and independent of a consumed current, and a current source – an output current is constant and independent of an output voltage. In real conditions there will be some limitations, especially in the consumed power. That is why the sources have limitations – the voltage source has the limited current and the current source has the limited voltage. Also, the device must have an overload indicator with light and sound.

The first version of the developed source is not used anymore. It had a USB connection for power and control. The output was controlled by a PC. But using a USB as a power source was not the best solution. The major drawback was that a USB interface could not handle the sharp changes of the consumed current, even all parameters were below limitations. Because of that these devices were used only for one year.

Because of the unreliability of the first DC source, a more stable DC source was designed (Figure 12). It consumes power from an ordinary 220V AC power network through an AC/AC power transformer. The device has two independent voltage sources and one current source. They have a common ground terminal. The parameters of the device are shown in Table 3. Outputs are stabilised; also they are protected against an overload. The state of outputs is indicated using LEDs and a buzzer. When the output acts normally, the colour of a LED is green, otherwise the buzzer will sound and the colour changes to red. The structure schematic is shown in Figure 13. The device consists of rectifiers and voltage and current stabilisers. Also, it has overload detection and a protection circuit. All components of the devices are packed into a plastic case 23×12×38 cm.

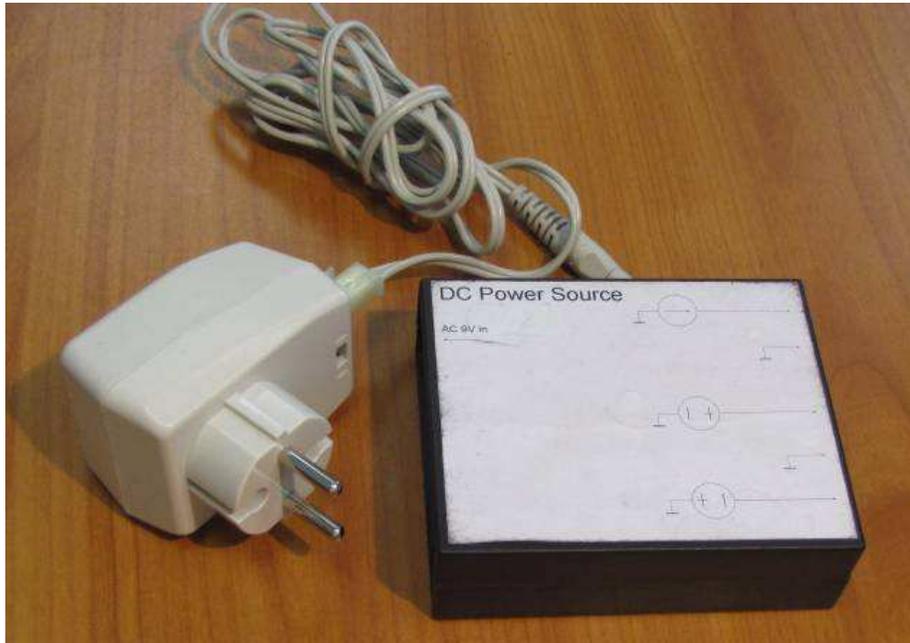


Figure 12 DC power source

Table 3 Specification of the DC source

Voltage source 1	
V _{out}	5V
I _{max}	400mA
R _{out}	0.5 Ω
Voltage source 2	
V _{out}	-5V
I _{max}	400mA
R _{out}	0.5 Ω
Current source	
I _{out}	5 mA
V _{max}	24 V
R _{out}	100 kΩ

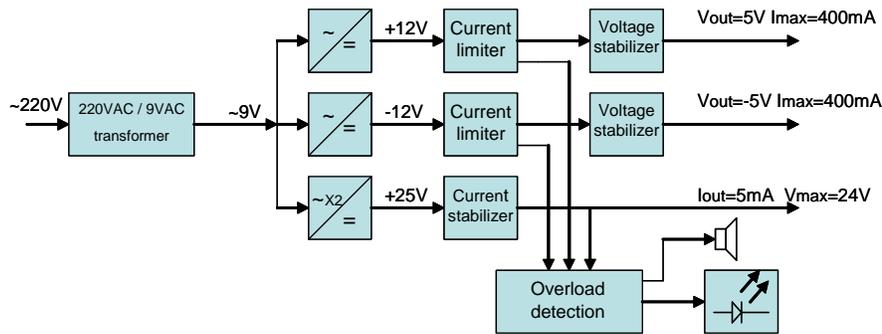


Figure 13 Structure schematic of the DC source

3.3.2 Three-phase AC supply

A three-phase AC power supply (Figure 14) is intended primarily to explain the three-phase power grid system. It can be also used as a one-phase ordinary AC power source. The device is powered also from an ordinary 220V AC power network through an AC/AC power transformer. The output is generated using a small microcontroller ATtiny26 [47]. The output is a three-stage approximated sine waveform (Figure 15). The reason to use the simplified sine is simple – high efficiency and the simplicity of a circuit [50], [51]. Also, this waveform has the parameters very close to a real harmonic wave. The output can be written using the formula (2).

$$f \approx \sin 2\pi ft - \frac{1}{5} \sin 5 * 2\pi ft - \frac{1}{7} \sin 7 * 2\pi f + \frac{1}{11} \sin 11 * 2\pi f + \frac{1}{13} \sin 13 * 2\pi f \dots (2)$$

It differs from an ordinary square wave by the missing 3rd, 9th, 15th, 19th, etc. harmonics (Figure 16).



Figure 14 Three-phase AC source

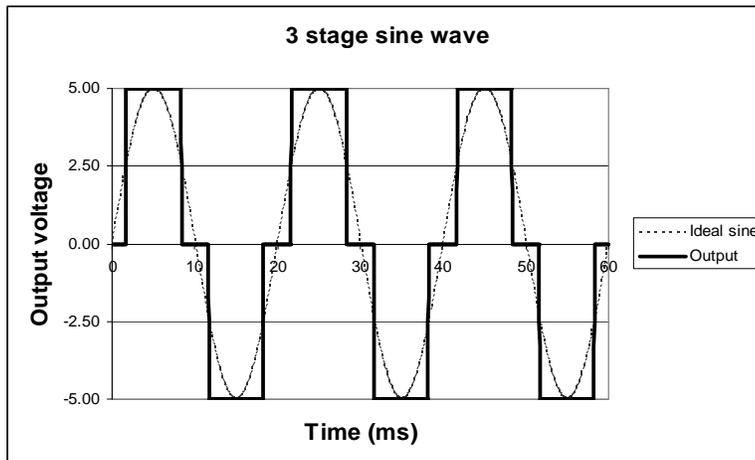


Figure 15 Three-stage sine waveform

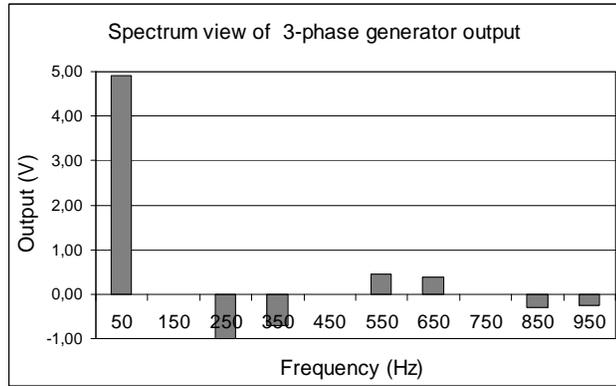


Figure 16 Spectrum of the output of the AC source (negative values indicate the phase shift 180°)

The frequency has been chosen 50Hz because most multimetres show values correctly in that frequency. That is why ordinary multimetres can be used. The device has three equivalent outputs with a phase shift 120 degrees.

The parameters have been shown in

Table 4. Using a microcontroller enables to change the parameters of the output (the frequency, the waveform) easily. The power supply is also protected against the overload indicated by a LED and a buzzer sound. The structure schematic is shown in Figure 17.

Table 4 Parameters of the AC source

Phase Voltage	4.1 V
Line Voltage	7.2 V
Maximum current	600 mA
Frequency	50 Hz
Phase shift	120 degrees

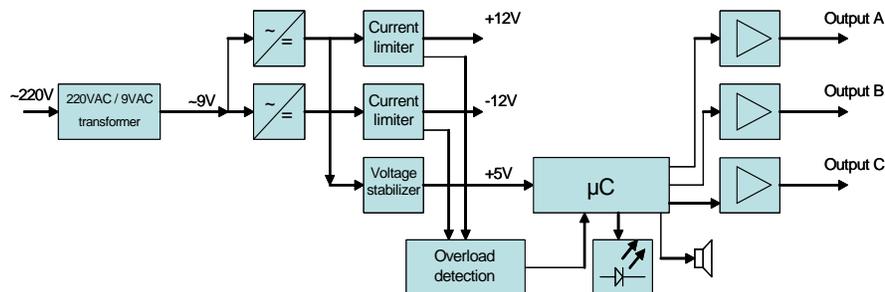


Figure 17 Structure schematic of the 3-phase AC source

3.3.3 AC generator and scope

The most sophisticated device is an AC generator and a scope (Figure 18). The device is designed because of very high prices of industrial scopes. Industrial scopes and generators are too difficult to understand and operate, especially for a novice student. When designing, there was presumed that the user interface must be in a PC, which gives great flexibility in creating a specific user interface (with a different step of difficulty). The device is connected to the computer using an ordinary USB 1 connection (also works with a USB 2). The physical limitations of the device have been shown in Table 5. The structure schematic is shown in Figure 19. The device has a digital part and an analogue part.

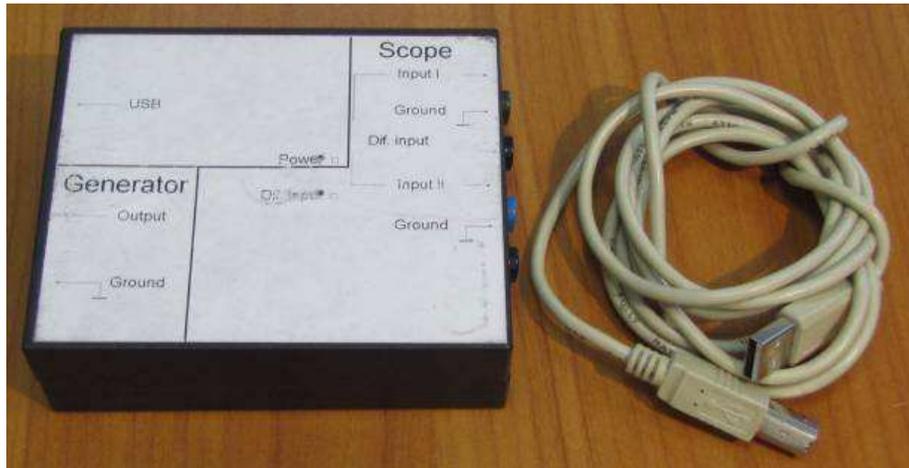


Figure 18 AC generator and scope

The firmware for microcontrollers was designed by Antti Sullin in his master work in 2007 [48] under the guidance of the author of the present work. The digital part consists of two microcontrollers AtMega88 [49]. One is used for the USB interface; another is used as a generator and a scope. The analogue part is designed by the author of this dissertation and consists of amplifiers, a synchronising circuit and a power supply.

The user interface has also been created by the author of this dissertation. Because of the computer interface, flexible software can be designed. There have been designed two similar versions of software – one for Windows 98/XP and another for Windows Vista/7. Their interface (Figure 20) looks like an ordinary analogue or a digital scope and it is very easy to use.

Table 5 Physical limitations of the AC generator and the scope

Output voltage	4V p-p max
Output resistance	110 Ω
Output waveform	Any kind
Output frequency	10Hz – 30kHz
D/A converter	8 bits
Number of inputs	2
Input resistance	>1M Ω
Max input voltage	8V p-p
Input frequency range	10Hz – 30kHz
A/D converter	8 bits
Input amplification	+20dB (selectable)
Synchronization	Generator/external

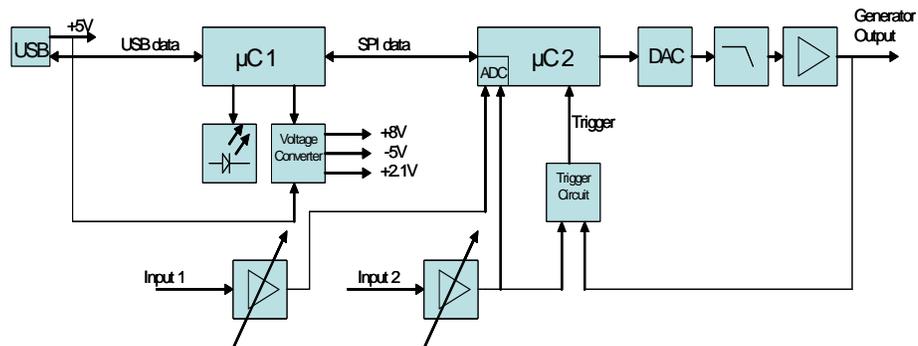


Figure 19 Structure schematics of the AC source

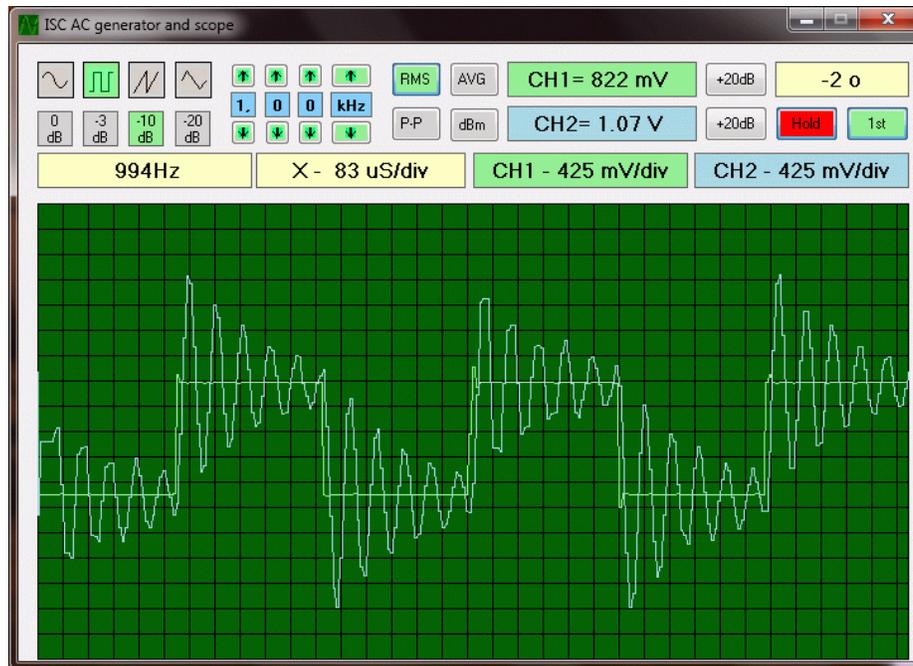


Figure 20 Screenshot of the AC source software

3.3.4 Operational amplifier

An operational amplifier is the one of the most important devices in electronics. The main reason why the opamp device was designed is because industrial operational amplifiers do not have laboratory connectors. Also, they have good parameters and therefore measurement needs expensive equipment.

Since the purpose of a lab task is to show how an operational amplifier works, the opamp device (Figure 21) acts like a normal opamp but all parameters are intentionally decreased. They can be measured using the scope. The structure schematic is shown in Figure 22. The device consists of a differential input amplifier, an adjustable low pass filter and an adjustable output amplifier. That means that amplification and the cut-off frequency can be adjusted. Also, it is possible to make it unstable with a 100% feedback [52]. The opamp device is powered from a 9V AC adaptor. Both input and output are protected. The parameters of the opamp and the comparison to the widely used opamp TL071 [53] is provided in Table 6.



Figure 21 Opamp device

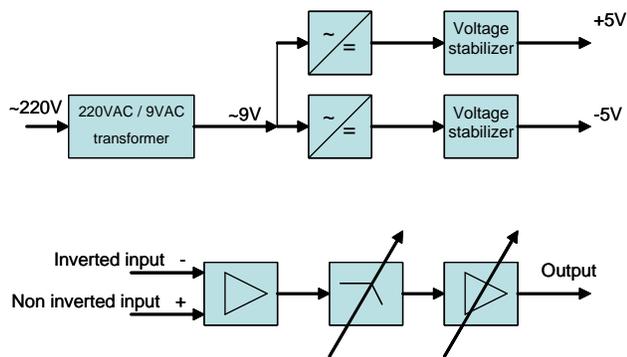


Figure 22 Structure schematic of the opamp

Table 6 Opamp parameters

Parameter	OPAMP lab device	TL071
Input resistance	1M Ω	>1G Ω
CMR	30 dB	86 dB
Rise time	0.5 ms	0.1 μ s
Bandwidth	3–10kHz	4MHz
Gain	10–100	>20 000
Max. output current	50mA	20mA
Output voltage swing	+/- 5V	+/- 12V

3.3.5 Twopole, twoport, fourpole and transformer

The HomeLabKit includes some specific devices needed to conduct lab experiments in the circuit theory [54], (Figure 23). Similar devices have been used since the early 1980s [55], [56] and the main idea has not changed. Of course, the designed devices have different parameters which are stored in a database. The parameters have been chosen to match the essential parameters provided in Table 2 (see page 36).

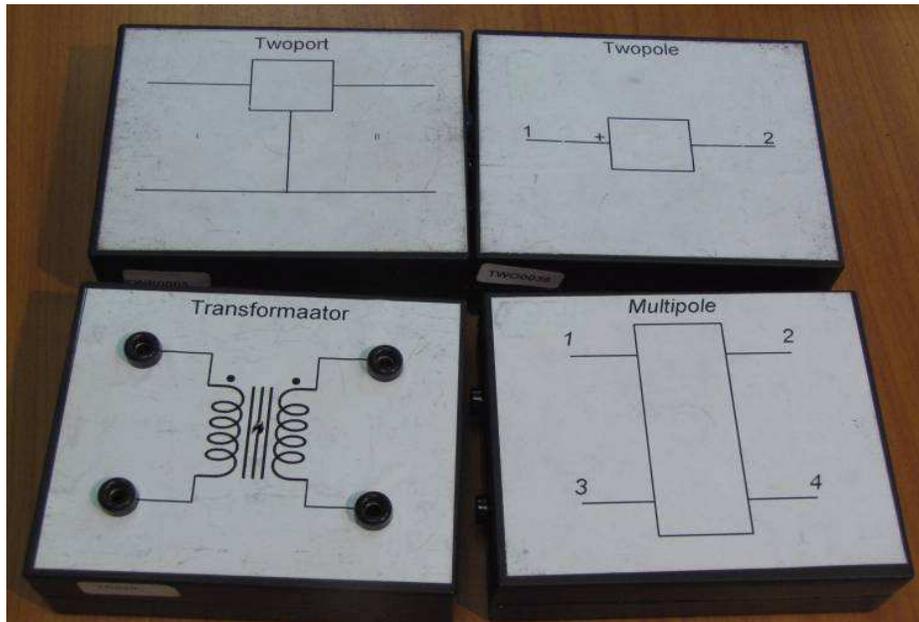


Figure 23 Course specific devices

The twopole contains a battery and a resistor to increase the input resistance. The device is used in labs to learn the Norton's and Thévenin's circuits. The different devices are produced by varying the polarity and voltage of a battery and also the value of a resistor.

Twoports and multipoles are used to measure their parameters (Z , Y , H , $ABCD$). A multipole can also be used as a twoport and twoports can be connected together to measure transmission parameters. The central body components of those devices are ordinary resistors connected as an equivalent circuit. By varying them, a number of different devices were developed.

A transformer is used to measure its characteristics and it is implemented as an inductor, if necessary. Small-size power transformers are used and different transform ratios are obtained using different coils of transformer.

3.3.6 Two-terminal components

Separate elements (Figure 24) such as resistors, capacitors and inductors are used in all labs. For an easy and comfortable usage they are mounted into a plastic pipe. At the both end they have connector terminals. All components are labeled randomly and they do not correlate with their real values. The values for each kit are carefully selected in consideration the components and their different combinations match the parameters provided in Table 2 (see page 36).



Figure 24 Resistors, capacitors and inductors

3.3.7 Types and content of HomeLabKits

The devices are packed into special boxes of size 90×110×35 mm [57] (Figure 25). There were 5 different types of lab kits which were used in 2009:

1. the HomeLabKit for bachelor students,
2. the HomeLabKit for master students,
3. the lab kit for bachelor students,
4. the lab kit for master students and
5. the lab kit containing measuring instruments and connection wires.



Figure 25 HomeLabKits – the external view

At the beginning of the year 2010, there were 73 sets of kits available in total: 33 HomeLabKits for bachelor students, 6 HomeLabKits for master students, 14 lab kits for bachelor students, 5 lab kits for master students and 15 instrument kits. The customized HomeLabKits are properly equipped to carry out labs in bachelor or master courses (Figure 26). Besides, there were 14 kits developed for using in lab rooms.



Figure 26 HomeLabKit – opened

The lab kits differed from the others by the absence of instruments. The instruments were provided in a separate kit. When doing a lab assignment, the

student had to use two kits: a lab kit either for a bachelor student or a master student and a kit containing instruments.

Lab kits and HomeLabKits for bachelor students contain:

- 4 resistors (resistance from 100Ω and $1k\Omega$),
- 2 resistors (resistance from $10k\Omega$ and $50k\Omega$),
- 1 adjustable resistor ($5k\Omega$),
- 1 inductor (inductance from $50mH$ to $150mH$),
- 2 capacitors (from $1nF$ to $56nF$),
- 1 autonomous twopole,
- 2 twoports.

Lab kits and HomeLabKits for master students contain:

- 1 multipole,
- 1 transformer,
- 1 operational amplifier,
- 2 resistors (resistance from $10k\Omega$ and $50k\Omega$),
- 2 capacitors (from $1nF$ to $56nF$),
- 2 precision $1k\Omega$ adjustable resistors.

The values of components were separately selected to match the requirements in Table 2 (see page 36). In order to help select those, a special web page with helpful scripts and calculations was designed (Figure 27). HomeLabKits include also the equipment from the instrument kit.

The instrument kit contains:

- an AC generator and a scope,
- a 3-phase voltage source,
- a DC power source,
- a 9V AC power transformer (adaptor),
- 9 connection wires equipped with lab connectors,
- a USB cable,
- a digital multimeter M830,
- an analogue multimeter AVM370.

CTLabKitting asp - Windows Internet Explorer
 http://isc.dcc.ttu.edu/NET/Teacher/CTLabKitting.asp

File Edit View Favorites Tools Help

CTLabKitting.asp RespondMail.asp Activities.asp CTLateBoxes.asp

Main Mails Student LabsKitting LabsList LabsSummary

KIT315	11/19/2008	6/15/2010	DeviceID	R	DeviceID	R	DeviceID	R	DeviceID	
BSc,Home	9:28:48 AM	11:35:00 AM	R001	110	R054	180	R912	10000	RES0037	
LOCKED	<input type="button" value="UNLOCK"/>		R003	130	R059	300	R913	22000	RES0040	
BoxID=127			R008	220	R063	430	R914	33000	RES0042	
AC source and scope	ACS	AC0115	R010	270	R065	510	R915	8200	RES0044	
Analog multimeter	AMM	AM0116	R011	300	R067	620	R916	22000	RES0046	
Capacitor	C1	CAP0181	R015	430	R069	750	R917	47000	RES0048	
Capacitor	C2	CAP0326	R016	470	R071	910	R918	10000	RES0049	
DC source	DCS	DC0118	R017	510	R072	100	R919	22000	RES0053	
Digital multimeter	DMM	DM0120	R019	620	R075	130	R920	33000	RES0054	
Inductor	L1	IND0046	R022	820	R078	180	R921	10000	RES0056	
Variable resistor	POT	POT0119	R023	910	R097	111	R922	47000	RES0060	
Resistor	R1	RES0500	R024	100	R098	120	R923	33000	RES0061	
Resistor	R2	RES0272	R026	120	R900	8200	R924	33000	RES0062	
Resistor	R3	RES0071	R030	180	R901	15000	RES0001	9750	RES0065	
Resistor	R4	RES0438	L=69 R=275 CAP0181 & RES0080 405.00 [us] 0.39[kHz] 103							RES0066
Resistor	R7	RES0080	R03 CAP0181 & RES0017 222.00 [us] 0.72[kHz] 152							RES0067
Resistor	R8	RES0017	R03 CAP0326 & RES0080 91.26 [us] 1.74[kHz] 560							RES0072
Twopole (active)	TWO	TWO0006	R03 CAP0326 & RES0017 50.02 [us] 3.18[kHz] 336							RES0074
Twoport	TWP1	TWP001	R040	470	R906	8200	RES0018	154	RES0075	
Twoport	TWP2	TWP026	R041	510	R907	15000	RES0026	32200	RES0077	
<input type="button" value="Refresh"/>			R043	620	R908	33000	RES0027	26600	RES0078	
			R050	120	R909	9100	RES0033	333	RES0083	
			R051	130	R910	15000	RES0035	9700	RES0084	
			R052	150	R911	33000	RES0036	390	RES0086	

Component

BSc

KIT100	KIT101	KIT102	KIT103	KIT104	KIT105	KIT106	KIT107	KIT108
KIT109	KIT110	KIT111	KIT112	KIT113	KIT114	KIT115	KIT116	KIT204

Figure 27 Screenshot of a lab kitting web page

3.4 HomeLabKit usage and statistics

The HomeLabKit is used since 2005. The first version was a simple copy of the lab kits used in a classroom and it was released for the testing purpose. There were only 25 kits assembled for the labs conducted at Kuressaare College. The lab assignments were traditional and students made 114 attempts (only 7 lab assignments were conducted during the course and they were not repeated).

In 2007, traditional labs were replaced with simple lab experiments. The labs were splitted into single lab experiments. Lab assignments were still done using the first version of the HomeLabKit. Its usage grew significantly. There were made 15,362 lab attempts during a semester (Figure 28). Also, home lending was started. Since the quantity of kits was limited (25 kits) and the same kits were used in a lab, the students who could get the HomeLabKits were selected.

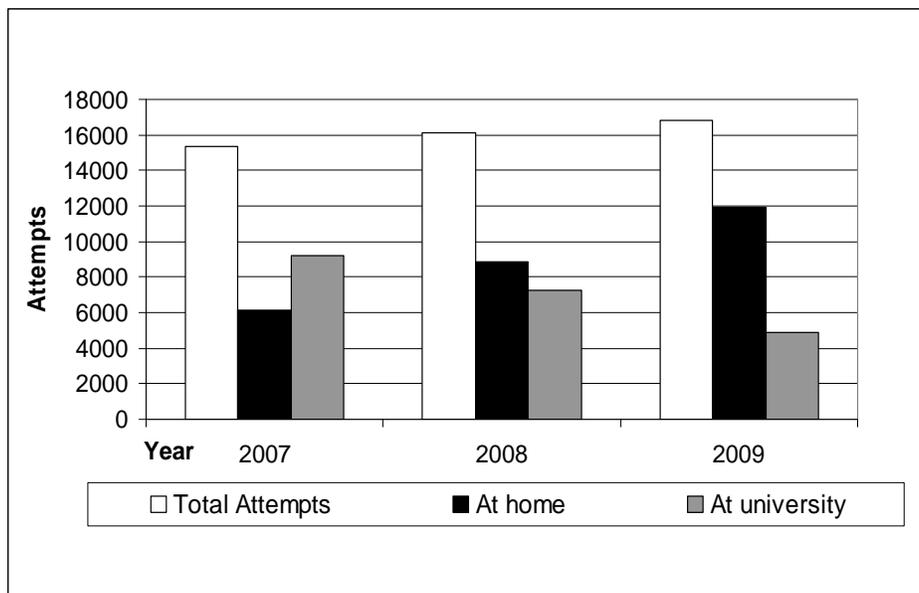


Figure 28 Lab attempts using the HomeLabKit

The most popular way was “overnight lending” (Table 7), i.e. a student took his HomeLabKit in the evening and returned it next morning. Although that type of lending was convenient, it had a drawback. Namely, there were students who did not return their kits on time. Since the same kits were used at labs, the delay caused timing problems. The solution to the outstanding problem came in 2008 when using the customized lab kits for home and for university was started. However, lending problems continued due to the increase of the proportion of home activities. In 2007, approximately 40% of labs were conducted at home.

Then, the number increased rapidly, reaching 55% in 2008 and 71% in 2009 (Figure 28).

Table 7 Home laboratory lending statistics

	Year		
	2007	2008	2009
Average lending time (days)	1.9	6.6	4.7
Average attempts per day	27	10	13
Total no. of lendings	213	262	592
No. of lenders	90	104	169
Number of total active students	117	124	212
Percent of lenders	76.9%	83.9%	79.2%
Max. no. of lendings per student	10	9	11
Average no. of lendings per student	2.45	2.54	3.5
Overnight lendings	41.78%	6.49%	6.42%

Initially, it was assumed that the kits would be used mainly as home labs and by limited number of students. But in reality, the following three usage modes were applied.

1. Using the kits as home labs – a student took the kit and performed his/her labs fully at home. The time needed depended on all activities as assignments were logically dependent. 30 kits were used for home labs and the kits were reused by other students. In 2009, there were 6 students out of 60 who conducted their lab activities in the full extent at home (Figure 29).

2. Using the kits in a lab room – the majority of students visited lab rooms at university as they needed guidance in assembling circuits, getting familiar with meters, etc. Also, the students used the kits in lab rooms when they did class tests.

3. Short-time lending – students took kits for a night or few days, preferably for a weekend. This type of home lending appeared to be the most popular mode (Figure 30). To be specific, since the number of kits was small in 2007, overnight lending was predominant. In Figure 30 it is shown as 0 days. Some long lending times (more than a month) were omitted because these were special cases (distant learners).

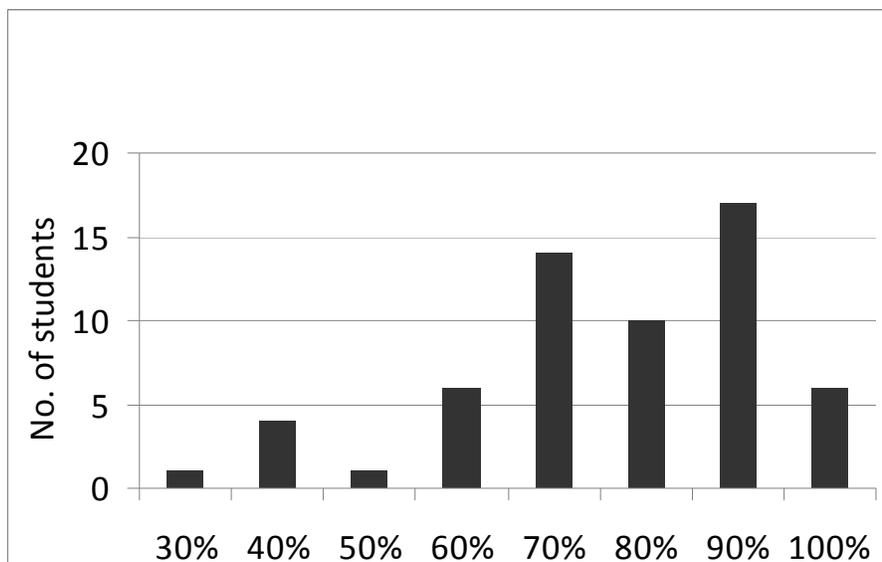


Figure 29 Amount of home activity in fall semester 2009

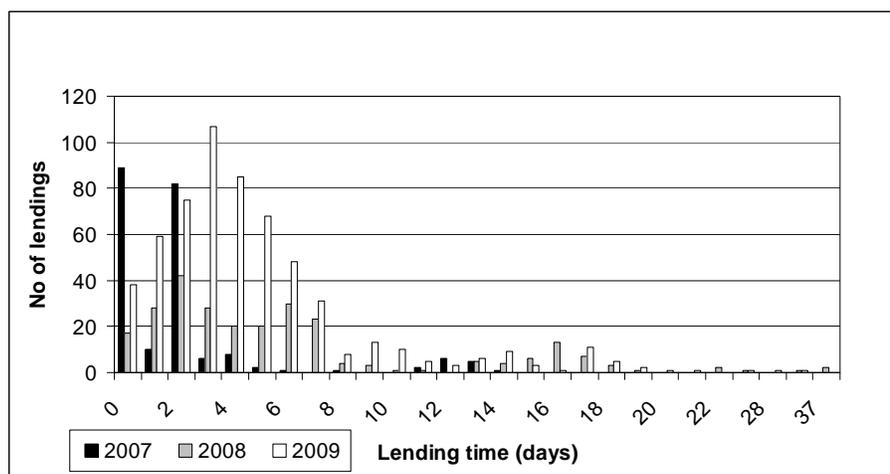


Figure 30 Lending time

The percentage of carrying out labs at home had increased and reached in fall semester 2009 the following distribution: the largest group had performed 90% of learning time at home, the next group – 70%, the third group – 80% (Figure 29). It could be noted that the students' learning time comprised experimental work, consulting, discussion and class works. Only 2 classical lectures were given in the beginning of a semester.

When lending kits, the human factor should be taken into account. Students had to register to use kits. Then they were allocated a time slot to conduct their assignments. At that time, the kits were not available for others and if they registered, they stayed in a queue. The queue moved up when the status of kits was released. The longest queue was in December 2009 when over 30 students were waiting. Here, the following three problems occurred. Firstly, the student put himself/herself into the queue but for some reason (s)he did not take the kit. Secondly, the student did not return the kit on time. Thirdly, the student took a kit but (s)he did not use it.

To handle those problems, there were set some restrictions. Namely, the order of a kit was cancelled when the kit was not taken in time (usually the time for taking was 24 hours). If a student did not bring the kit back on time, his/her all activities were blocked until the kit was returned. If a student did not do any assignments with the kit, (s)he had a delay when (s)he registered to a kit (but (s)he could do his/her assignments in a lab).

The overall home lending statistics is shown in Table 7 and Figure 30. The numbers in the table are from fall semesters. The table includes all students (even those who did not get the final mark) and attempts. There are omitted some very long lending times (more than a month) because these are individual cases. The overnight lending and a short lending time were very popular in 2007 because of a limited amount of kits. Also, it explains why the average of the attempts per day was higher than in the following years. In Figure 30 the overnight lending (the lending time is less than a day) is shown with the first bars.

Over 75% of students used the HLK at least once during the course. The slight decrease in the lending figures could be explained with a large amount of students in the fall semester 2009 (there were some changes in the syllabus of the course). As for the students who got the final mark, all of them had registered to lend the HLK at least once and it was common to all years.

4. Creation of lab assignments

This chapter includes seven sections. First, the historical notes on the relevant topic are given. Section 4.2 introduces the concept of elementary lab experiments. Next, the importance of lab assignments is pointed out. In section 4.4 the structure of lab assignments is presented. Next section covers processing lab results. Students' behaviour is also under attention. Finally, the teachers' role is described.

4.1 Historical notes

Although the course “Introduction to electrical engineering” was converted to the e-mode in the early 2000s, the labs were traditional. The main difference was the absence any paper documents in lab reports. A student had to pass 7 lab works of different complexity and structure. The first labs had to be completed during a fixed time slot (usually 90 minutes), some labs needed additional homework (after measurements were completed, calculations had to be done at home). Labs were linearly ordered and a student had an access to the next lab only after the previous lab had become into the state “done” (Figure 31).

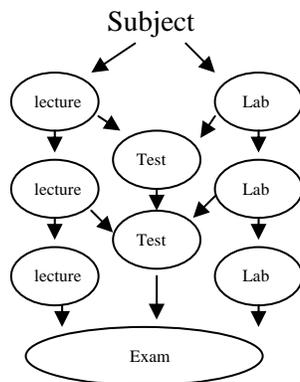


Figure 31 Lab assignments until 2006

A lab report was composed using the Internet form that was saved in a database automatically. The advantage of web-based labs lay in the following: if possible, inconsistent data were shown in different colours and the report could

not be closed if any required field had been left empty. Measurements were made in the groups of two students but reports were individual and up to four aspects were evaluated by a teacher: preparation, measurements, homework and conclusions (Figure 32).

Aruanne

Tühispinge [V]	5.16	(mõõdetud)				
Tühispinge [V]	-5.18	(mõõdetud)	(inverteeritud polaarsusega voltmeeter)			
Takistus [ohm]	270	Pinge [V]	5.15	Vool [mA]	20	
Takistus [ohm]	310	Pinge [V]	5.15	Vool [mA]	15	
Takistus [ohm]	370	Pinge [V]	5.15	Vool [mA]	15	
Lühisvool [mA]	0.05	(mõõdetud)				
Lühisvool [mA]	-0.08	(mõõdetud)	(inverteeritud polaarsusega ampermeeter)			
Takistus [ohm]	270	Vool [mA]	-10	Pinge [V]	-2.79	
Takistus [ohm]	310	Vool [mA]	-9.5	Pinge [V]	-3.2	
Takistus [ohm]	370	Vool [mA]	-9.5	Pinge [V]	-3.82	
Takistus [ohm]	312.8	Takistusmagnisil seada 310				
Kommentaariid, selgitused, järeldused						

Pingeallika pinge [V] <input type="text"/> (mõõdetud)				
Mõõdetud resonantsagedus [kHz]	Arvutatud resonantsagedus [kHz]			
<input type="text"/>	<input type="text"/>			
Sagedus [kHz]	Mõõdetud V_L	Mõõdetud V_R	Mõõdetud V_C	Arvutatud vool (V_R/R)
0.000	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
0.000	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

NB!

Suuruste ühikud:
voolud [mA],
pinged [V],
takistused [Ω],
juhtivused [mS]

R=Ω L=mH
C=pF

Skeem nr 57

Sagedus [kHz]	Ülekande amplituud [dB]	Ülekande faas [°]
0.000	<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>	<input type="text"/>
0.000	<input type="text"/>	<input type="text"/>

Arvutused resonantsagedusel				
Muutuja	V_{rms} (efektiivväärtus)	V_{amp} (amplituudväärtus)	V_{avg} (mooduli keskvärtus)	
V_R	<input type="text"/>	<input type="text"/>	<input type="text"/>	
V_L	<input type="text"/>	<input type="text"/>	<input type="text"/>	
V_C	<input type="text"/>	<input type="text"/>	<input type="text"/>	
I	<input type="text"/>	<input type="text"/>	<input type="text"/>	

viga alla 1%, viga alla 5%, viga alla 10%, viga üle 10%

Kommentaariid, selgitused, järeldused

Figure 32 Previous complex lab assignments (in 2004)

This method had many disadvantages. The most serious disadvantage was that students had to pass lab assignments linearly. Also, the labs had a complex structure and were difficult to be understood. Besides, the lab assignments could not be repeated even in the case of an unsuccessful attempt. Also, it became clear that students tended to forget some information obtained during the previous labs.

The solution was splitting standard labs into micro labs where the lab consisted of a single attempt. The student had to do his/her attempt until (s)he succeeded. This idea works well with the HLK and using the student's memory model. Starting from the fall semester 2007, the lab experiments were organised as self-tests and class-tests using the same state model. There was introduced a large amount of simple experiments and processing methods to give instant feedback in the form of changing the ability level. As by that time labs had been based on the HLK for two years, the afore-mentioned developments could easily be implemented. The structure of the present learning environment is shown in Figure 33.

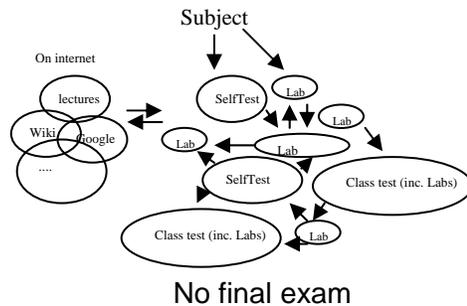


Figure 33 Structure of the present learning environment

4.2 Concept of elementary lab experiments

As noted above, the purpose of single lab experiments is to simplify learning. Therefore, the following requirements were written to single lab experiments.

1. The amount of acquired information should be as small as possible [58].
2. The number of (different) experiments must be as large as possible.
3. The lab experiment must be complete and independent from other experiments.
4. The feedback must be immediate and give instant reaction to a student.
5. A set of lab experiments must cover the competences required to pass

the course [59].

6. Each lab assignment can affect the student's state in multiple fields.
7. Each assignment must have the level of difficulty.
8. The probability of repeating the same assignment should be low.
9. A learning object must be interactive and collaborative for teachers and students [60].

4.3 Lab assignments

Competency-based learning is a method of study that focuses on what a person can actually do as a result of learning. It places a precise emphasis on the acquisition of competences during the learning process by matching competences to assignments [61], [62], [63].

The role of the teacher as a guide is challenging since the teacher has to identify the students' misconceptions about the material before (s)he can point them toward the experiments that contradict directly their erred beliefs about the topic [66], [67].

4.4 Structure of lab assignments

Complex labs are split into different lab topics. The topics are divided into micro-competences covering the whole subject. Each topic has a large amount of different lab experiments. The experiments are made as simple as possible. Each assignment has also a certain credit unit and keywords of skills and knowledge (competences). For example, if a student measures correctly the voltage, his/her knowledge increases also in composing circuits, understanding voltage units and also in calculation. In September 2010, there were totally 140 different single labs created, each of them had a lot of variations. Since all lab kits have a different content, the probability getting the same task and the same measurement result is relatively low. In addition, it could be considered as an efficient method against cheating.

In the following, an internal structure of lab assignments is described. The whole set of lab assignments are divided into lab modules (Figure 34). A lab module contains all lab assignments of a certain topic (e.g. Ohm's law). To produce different types of lab assignments, each module is divided into classes. In the class, the lab assignment is defined. It contains descriptions of a working sheet and also the main processing script. For adding different variations, each

class of assignments is divided into individual tasks. There can be set different parameters of assignments, for example using variations of schematic components.

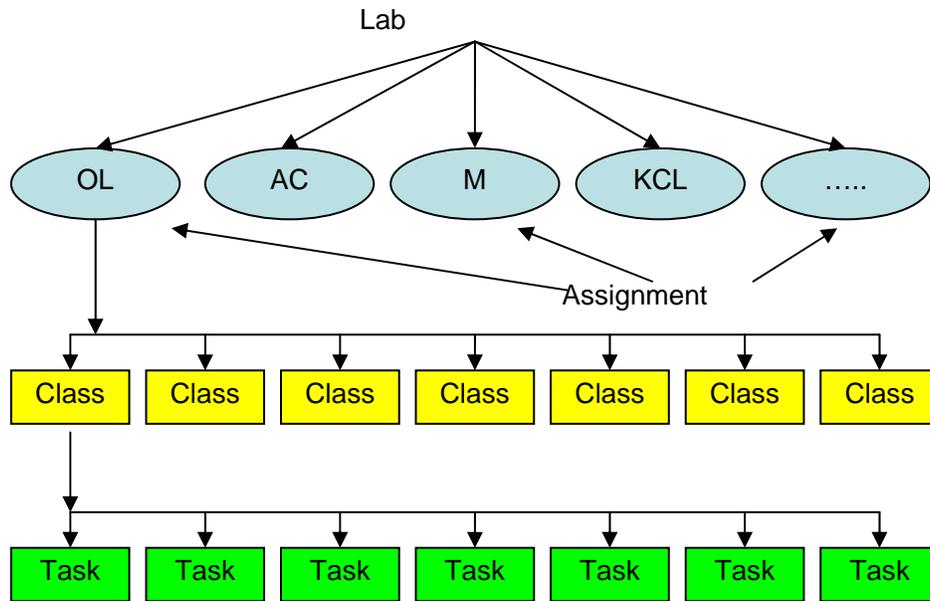


Figure 34 Hierarchy of lab assignments

Simple examples are shown in Figure 35 and Figure 36. The first one belongs to the class of the simplest assignments. Some of the first level tasks include a picture of the composed circuit. It helps to understand the relationship between a real circuit and schematics. Even this task consists of one measurement, it has competences in measuring the current, the usage of a multimeter and interpolating the sign of the answer.

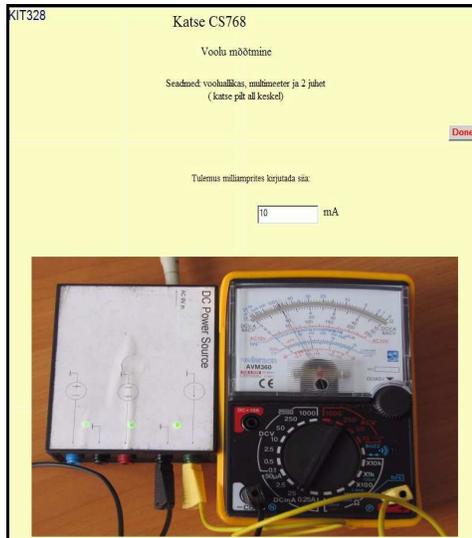


Figure 35 Current measurement

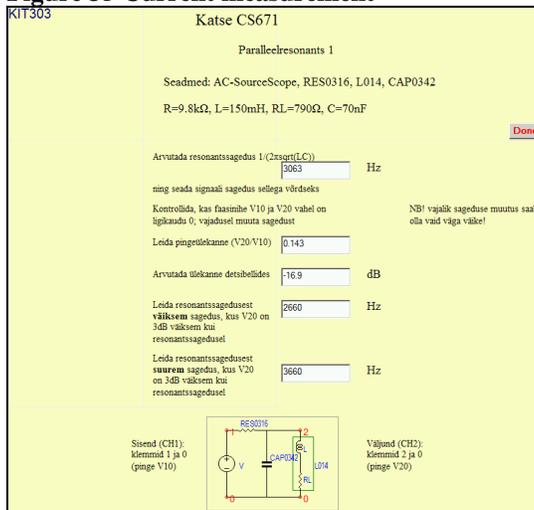


Figure 36 Resonance measurements

The second example (Figure 36) presents a more complex task. Before measuring the student has to calculate a value (in this case the resonant frequency) and perform measurements at this frequency. This assignment increases competences also in maths, because the frequency has to be calculated correctly. The calculations can be split into different components (units, dividing, a square root, etc). A full list of lab assignments and the related competences are in appendices.

4.5 Processing lab results

Handling lab results is supported by the automatically executed algorithms and the data generated by students. This data is a good source for the analysis and statistics [64], [65]. Analysing and creating processing scripts is laborious. Each answer affects different states of competences. But the advantage is that is a onetime activity.

Students' incorrect answers were examined. According to the analysis, the most frequent reasons for incorrect answers were of the following types:

- calculation errors,
- sign errors (a negative result was given as positive),
- measurement device errors,
- errors caused by the incorrectly composed test circuit,
- measurement unit errors,

There were numerous specific errors depending on the nature of the experiment, which are not listed here. The errors had different characteristics in each lab experiment. Based on the student's answer, the feedback signals (measurement results) were provided. The answer was compared with the expected answer and the environment showed the type of a possible error. Also, it provided learning materials (slide-shows, recorded problem solving examples, links to the Internet materials) as a signal to the learner.

To determine the error type, specific algorithms were used. A sign or measurement unit error can be determined easily. In these cases the answer has the opposite sign and/or can be multiplied or divided by 1000. In reality, students' answers are more complex and can contain different errors at same time.

In processing lab results the errors caused by a measurement device must be taken into consideration. There are two types of errors. An error caused by the accuracy of the device itself, and an error caused by its internal resistance. Knowing the parameters of multimeters, the estimated results are calculated. Also, it is possible to determine which type of multimeter is used, and in some tasks an analogue multimeter instead of a digital one can be forced to be used.

The amount of lab assignments has increased from 2007. In 2006, when using traditional labs, each student carried out 7 lab tasks. But after starting the simple experiment system, the number of attempts increased. The students who got a final mark made 13,362 lab attempts in 2007, and the number of attempts was 16,108 in 2008, and 16,817 in 2009. Those numbers show the attempts made by the students participating in the course "Circuits systems and signals" in the fall semester (Figure 28, see page 52).

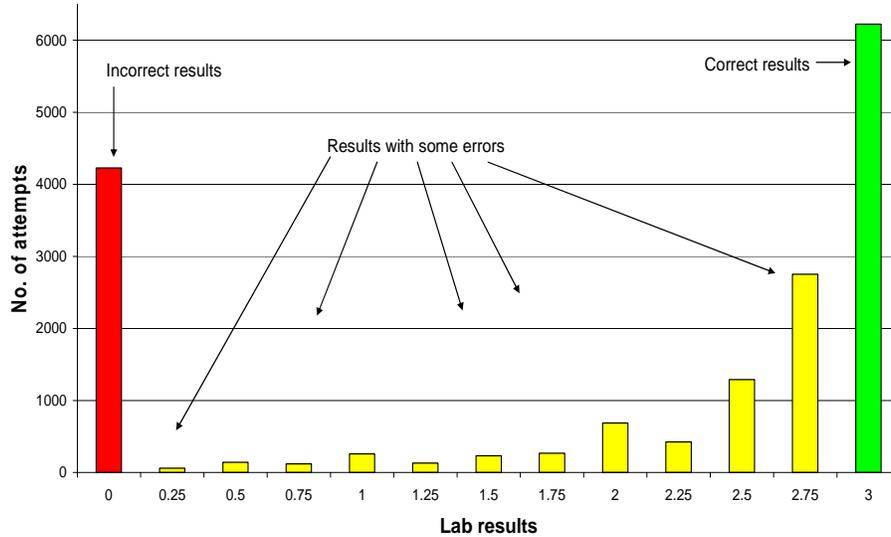


Figure 37 Correct and incorrect lab results

During the fall semester 2009, totally 16,817 attempts with lab kits were performed. The amount of total attempts of the students who had reached the final mark was significantly higher than of those who had not completed the course by deadline. The large number of attempts is demonstrating the students' guessing behaviour and cognitive learning [16]. From all actions 29% was made in a lab and 71% at home (in 2008, respectively 45% and 55%). It is interesting that the percentage of incorrect answers is 49.4%. It can be explained by the fact that it concerns the students who completed the course by the end of a semester.

The result of the lab or test is evaluated by a numerical value in the range [0.0, 3.0] as 3.0 means absolutely correct and 0.0 is an absolutely incorrect answer (Figure 37). All other cases are placed between them. Including some measurement errors, the answer is taken as correct if the result is larger than 2.8. Absolutely incorrect answers often contain more than one error and therefore it is difficult to determine the type of an error.

Now there are 12 different kinds of lab assignments. One experiment from the assignment "AC lab" could be given as an example here. The circuit which has to be composed is shown in Figure 38. The student has to measure a voltage gain and a phase shift at the given frequency. In addition, the student has to calculate the gain in decibels. All values of the components are stored in the database.

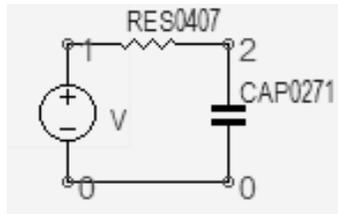


Figure 38 Circuit to be composed in the AC lab

The estimated values are calculated using the following formulas:

$$A = \frac{1}{\sqrt{(2\pi fRC)^2 + 1}} \quad (3)$$

$$A_{dB} = 20 \log(A) \quad (4)$$

$$\varphi = \arctan(-2\pi fRC) \quad (5)$$

where A is the calculated gain; dB is the gain in decibels and φ is the phase shift; R and C are the values of a resistor and a capacitor, and f is the frequency. The student enters 3 values: the measured gain, the calculated gain in decibels and the measured phase shift in degrees.

In this case, the measured gain should be less than 1 and the phase is negative. The gain in decibels should be also negative.

The measured values are compared with the estimated values using the processing script.

The phase check is carried out in the following way. If the phase is positive and the absolute value is correct, then there are 2 possible reasons:

1. the student forgot to write the minus sign,
2. the student mixed up the scope inputs.

Then, the calculated gain should be also larger than 1, and the estimated result is inversed. If the frequency is near to the corner frequency, it is possible that the student mixed up R and C. This can also be checked by calculating the estimated values with the “mixed” components.

The gain check is conducted in the following way. There is a possibility that a student has mixed up the measuring units. To calculate the gain, the input and output units must be the same. If the student errs, then the result is multiplied or divided usually by 1000.

The gain in decibels is checked in the following way. The calculations are easy to compare. The result has to match the estimated one exactly. But it is

checked also if the student has forgotten to multiply by 20 in the formula (4) or has used the natural logarithm by mistake.

Another good example is the error determination in the twoport measurements. Students have to measure the twoport parameters (mostly Z and Y) [54]. For example in 2009, there have been analysed 773 incorrect results. The students had to give the results for the y-parameters in mS and for the z-parameters – the resistance – in Ω . The most common types of incorrect answers are the following. The student does not know how to measure and hopes to pass by answering 0 or 1. Some errors are caused by the wrong assembling of the test circuit. For example, the student does not short another port while measuring the y-parameters.

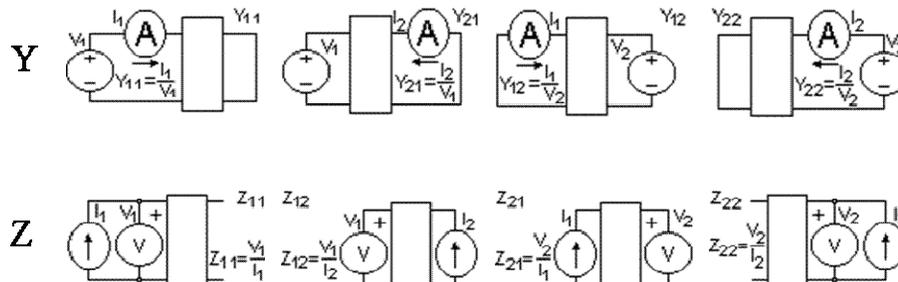


Figure 39 Schematics to be composed in the twoport measurements

There were 8 basic types of the results (shown also in Figure 40):

- the answer is 0 (the student does not know what to answer) – 34 attempts;
- the answer is 1 (the student does not know what to answer) – 22 attempts;
- the wrong parameter when measuring the y-parameters (maybe another port is open) – 179 attempts;
- the wrong parameter when measuring the z-parameters (maybe another port is shorted) – 224 attempts;
- very large numbers – the student has entered the numbers that exceed 1000 – 28 attempts;
- y12 or y21 have the wrong sign (they should be negative) – 64 attempts;
- the wrong measuring unit (k ω instead of ω) – 217 attempts;
- the negative z parameter (it is impossible in this circuit) – 5 attempts.

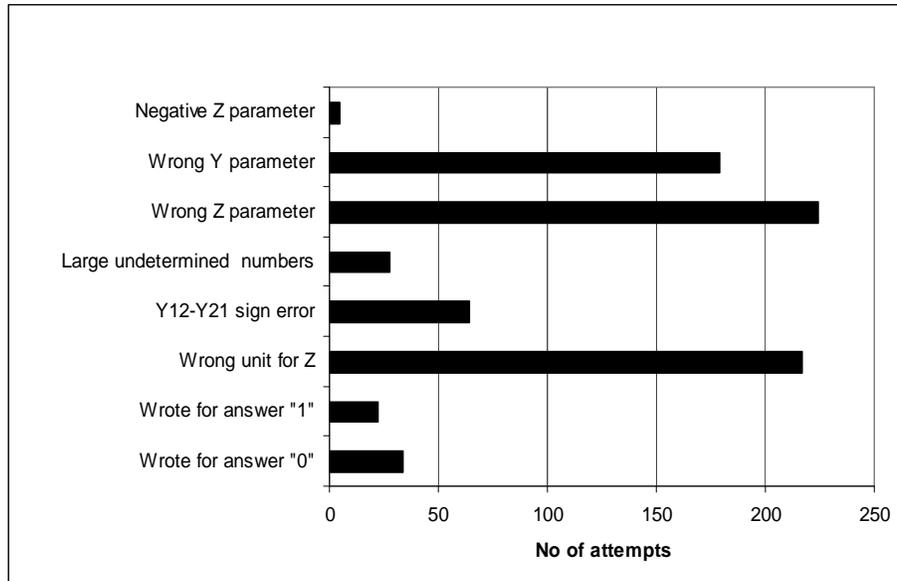


Figure 40 Incorrect answers in the twoport assignments

Analysing the lab results also shows the effectiveness of the lab assignment. The amount of attempts and results differs in labs. Here, the students who have completed the course have been considered. In Figure 41 and in Figure 42 are shown the correct and incorrect results by the lab topics. As seen, the number of attempts made at home is significantly higher than the number of attempts made at university. It can be explained by the time spent on conducting the lab assignments and the independence of lab assignments.

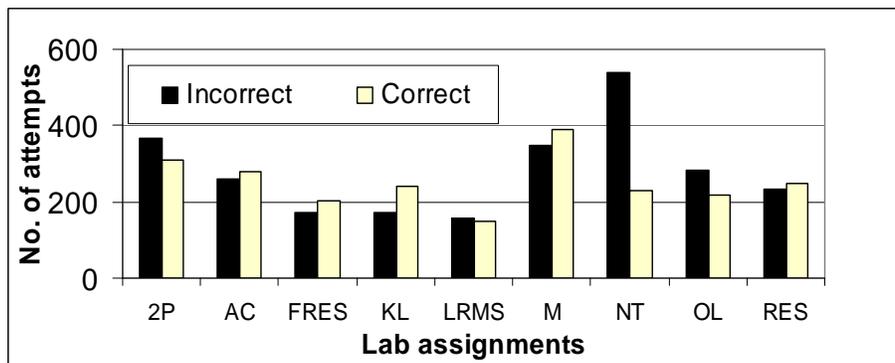


Figure 41 Lab attempts at university

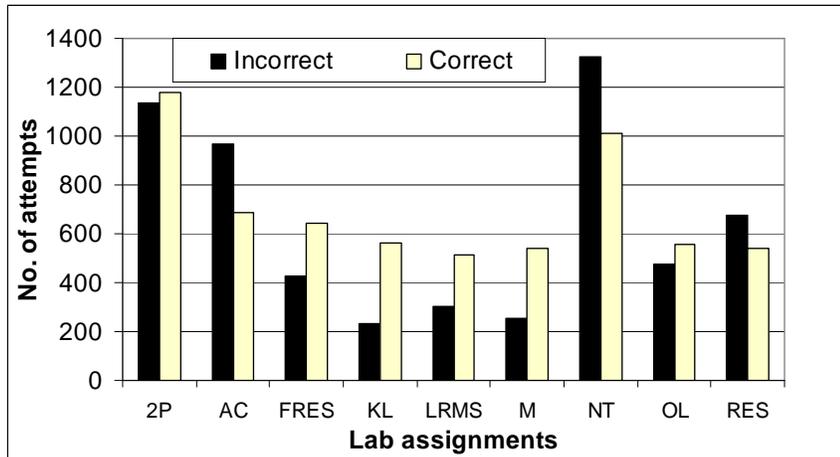


Figure 42 Lab attempts at home

Also, the number of attempts shows the difficulty of the current assignment. The similar values of correct and incorrect answers for “M” – the measurement conducted at university – can be explained as it is the first assignment to be conducted. The very high ratio of incorrect results in NT (the Norton/Thévenin transforms) can be explained that it is the first assignment where the student has to write the answer with the correct sign. In this assignment, about 90% of errors are the sign errors.

When we consider the students who completed the course, it is interesting that the maximum number of attempts was made to get the mark 4 (Figure 43). Also, it is noteworthy that the percentage of incorrect answers is almost independent of the resulting mark (Figure 44). There are small differences, but the average is the same.

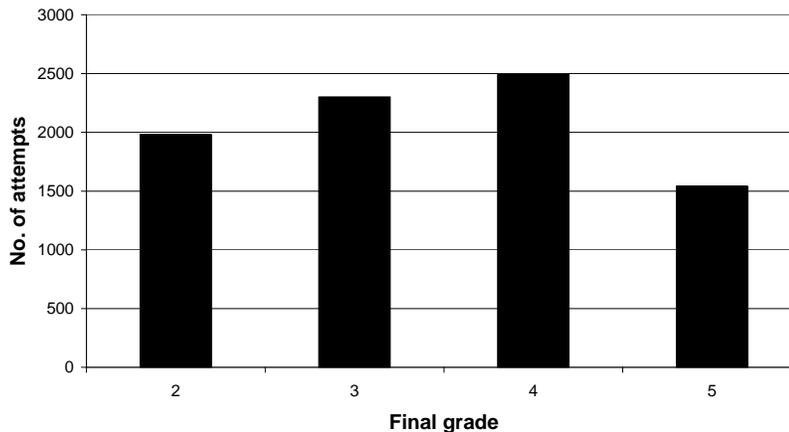


Figure 43 Number of attempts by the final mark

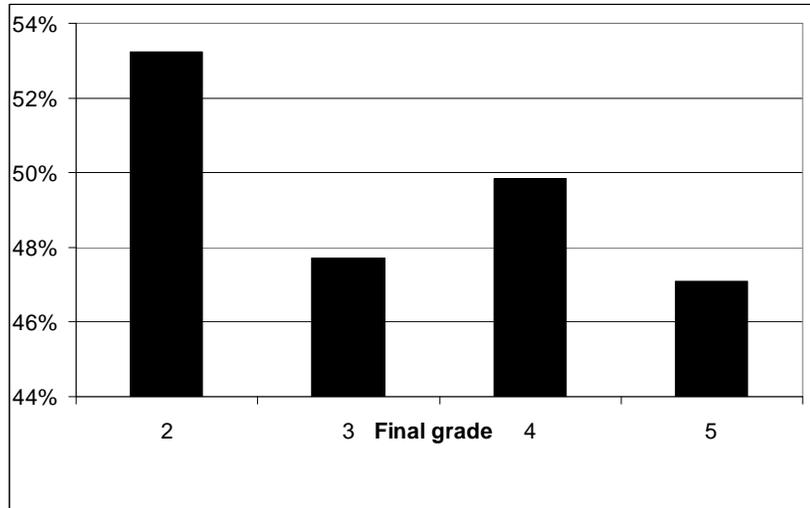


Figure 44 Percentage of unsuccessful attempts by the final mark

The slightly higher percent of wrong answers in “mark 2” can be explained by the existence a small group of the students, whose aim is to pass the course with minimum efforts. Another interesting higher rate in “mark 4” can be explained by the students’ attempt to move from mark 3 to mark 4.

4.6 Students’ behaviour

Students were not only asked about their opinion, but their behaviour has been analysed over the years. Some characteristics have been almost the same despite of the changes in the learning environment. In [68] can be found that e-learning does not change students’ learning style. Also, the learning style of a student is a powerful way of assisting the student in assimilating the knowledge from resources [69].

The length of a login in the examined years is analysed next. The length range of a login session was from 1 minute (checking messages) to 3 hours (intensive work). In [70] can be found that the highest probability of learning is 10 minutes after the login and the activity is approximately 35 minutes. That is why maximum 40 minutes time slots are used in classroom activities.

Also, the correlation between the activity and the time (in a 24-hour period) when the activity was carried out has remained the same over the years with maximum at noon and minimum at 5–6 a.m. (Figure 45). The higher numbers of attempts are between 10 a.m. to 14 p.m. It can be explained with the

activities carried out in labs and with the class tests. The overall activity curve is related to the learners' psychological characteristics. A similar activity curve is also found in [71]. During a week, the distinctive minimum of the activities performed was between 6 p.m. on Saturday and 6 p.m. on Sunday. This time slot is used for updates and the web site is closed for the students during these hours.

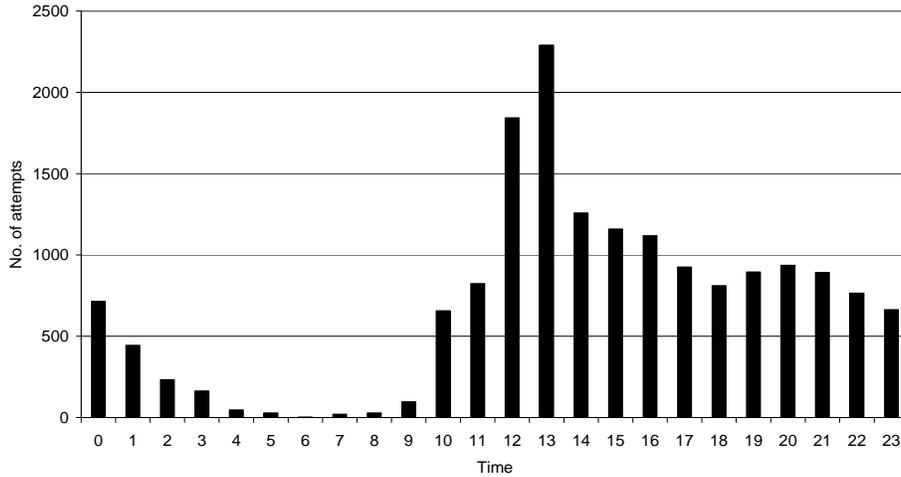


Figure 45 Lab attempts (in a day)

Similar patterns can be found in the curve of the students' activity during a semester. Here, the curve is approximated by the logistic curve (K-curve [26]). The amount of the assignments carried out can be calculated using the following formula:

$$N \propto \exp\left(\frac{t-t_0}{\tau}\right) \quad (6)$$

However, one can find differences depending upon the modes used in the particular course. Homework that is more time-consuming, usually not repeatable and would wait for human reaction, is postponed as far as possible (the K-curve [26], Figure 46). The time constant is relatively small and increasing ($\tau=0.87$ days) when mostly all assignments were postponed to the end of the semester.

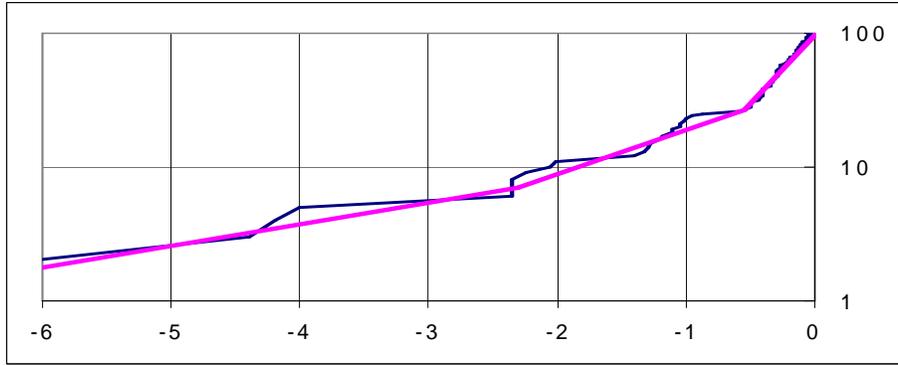


Figure 46 Homework submission before the deadline (Kukk's Curve 2003)

If a course is based mostly (or only) on interactive learning, then the logistic curve is smoother, and also, nearly a half of work has been done by mid-semester (Figure 47). The time constant is significantly larger ($\tau=58$ days, i.e. approximately 2 months).

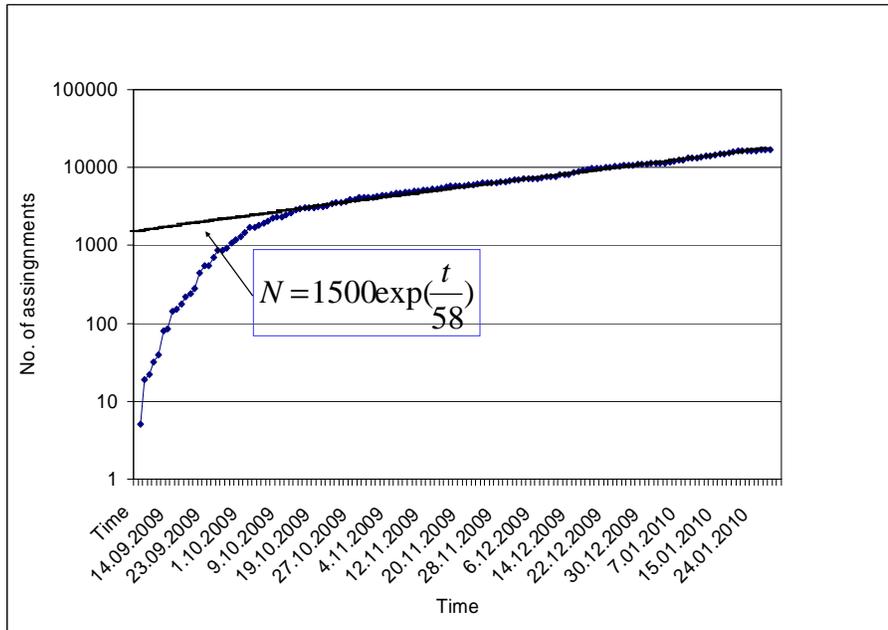


Figure 47 Amount of assignments performed during the fall semester 2009

The amount of the assignments carried out during a semester can be calculated using the following formula:

$$N = 1500 \exp\left(\frac{t}{58}\right) \quad (7)$$

Thus, it can be suggested to convert the traditional learning into interactive and to preserve homework in the classical form only in exceptional cases. Besides, students can perform almost all learning at the places selected by them. The only action that can be performed in fixed rooms (and at fixed computers) is class work (e.g. a partial exam), the frequency of which might range from 3 to 10 times (á 40 minutes) depending on the learner's learning style and psychological characteristics.

The students' overall time of learning is also different. The number of students (who passed the course) and the time spent in the learning environment is shown in Figure 48. The time shown on the arrow (140 hours) is the time formally provided for learning 3.5 credit units. Note that this graph does not show the time spent for learning outside the environment (e.g. reading books or searching materials from the Internet).

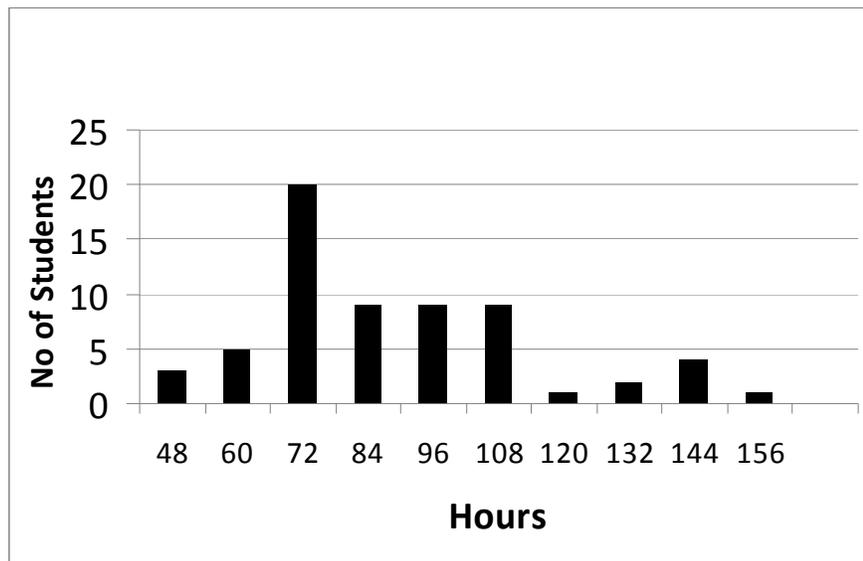


Figure 48 Overall use of the learning environment in 2009

At the same time, the number of performed assignments is relatively high (Figure 49). The average number of attempts made by 60 students who passed the course in the fall semester 2009 was 281 per student. There were 5 students who had made less than 100 attempts (the minimum was 66 attempts). The largest number was 659 attempts (it is shown in Figure 50 how they were

divided in time). Also, a significant growth of lab activities could be seen in the end of the semester. By the way, the first student achieved the mark 2 and the second student got the mark 5. The average time for an attempt was 3 minutes. The minimum was about 10 seconds, whereas the maximum was 25 minutes. Only 10 attempts took longer time than 10 minutes.

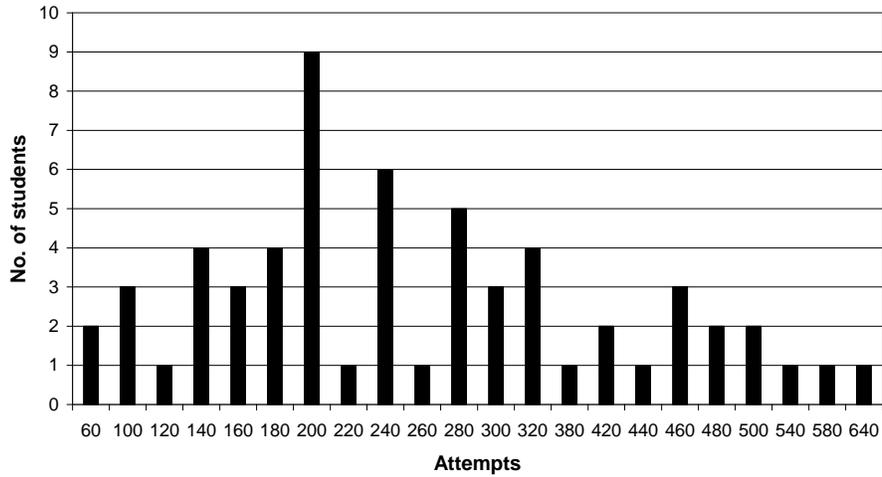


Figure 49 Number of performed assignments per student

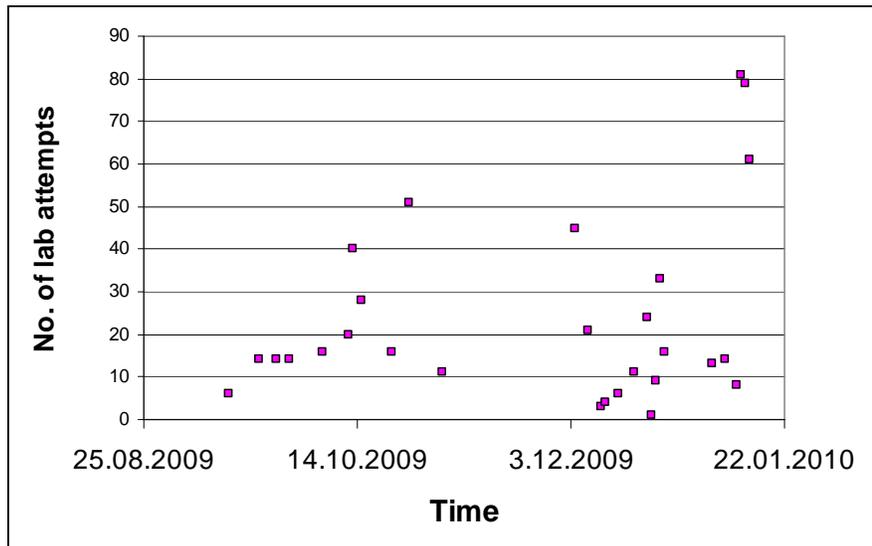


Figure 50 Number of lab experiments performed by one student (in the fall semester 2009). The dots show the days when attempts were made.

4.7 Teachers' role

The role of a teacher is changing. The main goal of a teacher is to help to learn and guide to appropriate learning materials [72], [73]. The main functions of a teacher are the following [76]:

- management – the teacher plans the learning program, which includes objectives, timetables, rules and procedures, content development and establishment of the practical work and interactive activities;
- intellectual function – this is the traditional teaching function; the teacher should know the syllabus and the particular subject;
- social function – this is considered as the fundamental function in e-training; the teacher should create a comfortable learning atmosphere, interact with the students and follow their activities. The teacher should animate, motivate and facilitate feedback. In order to fulfill this dynamic role, the teacher should design activities specifically for each objective and content, as well as motivating and encouraging the students.

Thanks to the e-learning environments, teaching becomes more personal [74]. In addition to the activities in labs, students can communicate with a teacher using the learning environment. In [75] can be found that there are no important differences between the functions of teachers in the two teaching modes, online and face-to-face; and if these differences do exist, they are likely to be due to the teacher's involvement and the institution's commitment in the programming of the learning process. In both modes, the importance of psychopedagogical, technical and organisational aspects of training has been shown. And the positively-valued tasks carried out by teachers are identical in both teaching systems, i.e., the facilitating of the teaching/learning process, combining the explanation of theoretical contents with activities, and encouraging interaction.

Compared to classical learning, the direct stress on teaching the staff has slightly decreased (mostly it is caused by the fact that the students perform labs at home). For example, in 2009, there have been total 275 activities: 102 class tests (micro exams, 40 minutes each) and 173 lab activities (45 minutes each). For each activity there were up to 16 work places available. Those numbers varied over the years and depended on the students' quantity and preferences. At the same time, the teacher's activity in the learning environment was relatively high (Figure 51). There were 4730 teacher's logins during three months (from November 2009 to January 2010, the data from previous years was not collected). The teacher's page is used to manage students and to communicate with them. The teacher's daytime graph correlates with the students' one. The maximum number of the teacher's activities was near the midday which was caused by the peak of the students' activities performed in a

lab (the teacher manages the activities in the real time). Other time is usually used to answer the students' questions. Immeasurable is the time needed to create the assignments, processing and testing algorithms, but a large benefit is that the results are processed automatically.

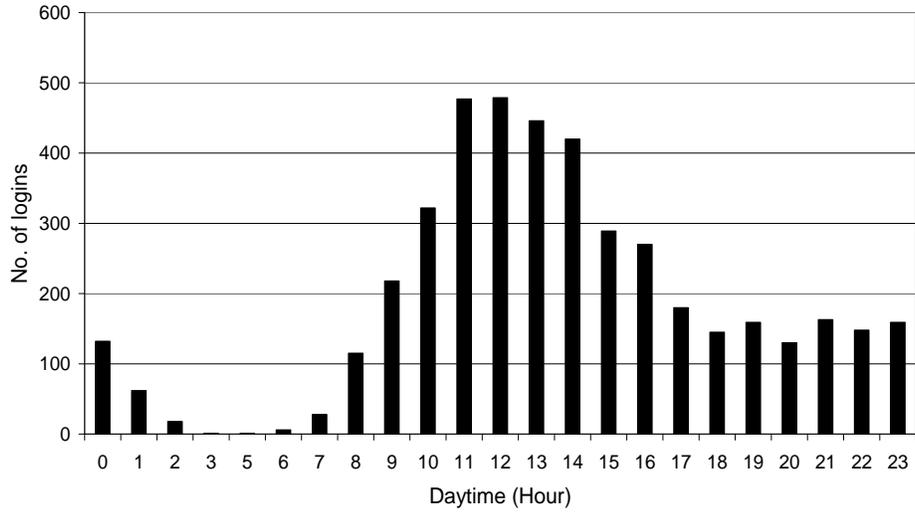


Figure 51 Teacher's activity log in the fall semester 2009

5. Student's memory model

The author's contribution is also student's memory model. In the first section of this chapter, the motivation of introducing the forgetting mechanism to students is described. Next, a short overview of memory models is given. Section 5.3 presents the first memory model implemented in the developed learning environment. Finally, the results and analysis of the related data from 2006 and 2007 are compared.

5.1 Motivation

From the fall semester 2005, the courses involved were transferred to the hierarchical assignment structure where a student had to start from the assignments of a lower level and moved up after completing the assignments successfully. In some cases, the structure represents a logical order, in some other cases, it replaces the time schedule. The structure supports keeping active a limited number of assignments, usually 2–5 (new) ones. Later, the course materials were organised in the way that a learner was directed only to those items that were needed for performing the currently active assignments. Of course, a learner can also open all materials, and then, more sources are available than needed to complete the particular course. All deadlines were abolished and contrary to the common assumption that students do nothing without strict deadlines, appeared to be not valid.

As every assignment was accompanied by certain credit units (0.1...0.40), it appeared to be a very motivating environment. However, clearer than ever before it came out that the feedback system targeting to the success in specific assignments may create temporary knowledge and skills. Before that model was applied, it was difficult to track such aspects.

This is why in the fall semester 2007, the forgetting mechanism was introduced, and the first one-semester experience showed that it was a successful action. Now, it is implemented where necessary and the model itself is being developed further using the data currently collected.

5.2 Memory models

Human forgetting has been studied for a long time. Probably, the first well-known experiments were provided by H. Ebbinghaus [77] in 1885. His experiments showed that retention is very fast in the beginning and quite slow later (following the exponential law); also, he showed how important is the repetition (rehearsing). Human memory mechanisms have been investigated in many works bringing to complicated models and proving the existence of different levels and types of memory (short-term, long-term etc).

In the developed interactive learning environment, a simple memory model is used inside the feedback loop. The model is being improved depending upon the results obtained. The application of complicated models (e.g. ACT-R [78]) in this case may not produce better results as there are many other factors, like the evaluation of the learners' abilities that are even more complicated.

In many sources, it can be found that memory models are used to predict the student's state and even mood [79], [80]. The goal in this research is to develop practical students' behaviour models [81].

5.3 First model

In this section, the ability (knowledge level) by the status that can have the values from some interval, for example [0,1], is being described. This status is used for the task selection and also in the forgetting model. To simplify the task selection, the discrete set [1...127] of values is used. The state 0 is used only for initiating and it never returns again.

If $S(t)$ is the current state and $S_i=S(t_i)$ is the initial state for the inter-session (forgetting) period i , then forgetting is modelled by the following function:

$$S(t) = F_i + (S_i - F_i) \exp(-(t - t_i) / \tau_i) \quad (8)$$

where F_i is the floor level and τ_i is the time constant for that period.

The parameters are valid from the end of a session (t_i) to the beginning of the next one when they are recalculated as follows.

If a new session starts at t_{i+1} , then a new task is chosen from the state $S=S(t_{i+1})$ (rounded to an integer). If the result of the solution is S^* , then the new time constant is calculated from the above equation:

$$\tau_{i+1} = -\frac{(t_{i+1} - t_i)}{\log\left(\frac{S^* - F_i}{S_i - F_i}\right)} \quad (9)$$

In case of $S^*=S_i$ (no retention), the time constant is multiplied by some constant, in our case 127. Two more corrections are determined at the end of a session. The floor value F_{i+1} is set equal to the minimum state obtained during the session, and the new state S_{i+1} is set equal to the last state in the session. So, the states in the following forgetting period are located in $[F_{i+1}, S_{i+1}]$. The time constant may become very small and this happens when the first test of the session shows an incorrect result.

It is possible that $S_i=F_i$ and then no forgetting is observed. It is questionable whether a student really achieves such status, but the memory theory claims that the long-term memory may be life-long. If the state is too low, a student has to continue to reach the threshold S_{th} marking a positive result. In practice, there was observed students' high motivation to increase S even when it was more than S_{th} (=77 in our case).

The initial values for any assignments were $S=0$, $F=0$, and $\tau=7$ days for self-tests and 28 days for labs.

5.4 Results and analysis (2006 vs. 2007)

As the student's memory model was introduced in 2007, the analysed data is from the fall semester 2007 compared with the data from the fall semester 2006.

In 2007, totally 134 students registered to the course where the interactive learning environment was implemented, and 125 of them started learning (i.e., had some assignments completed). By the end of the semester, 73 of them received the final mark. In the following, the data related to all 125 students was considered. In 2006, 151 students registered, 149 started, and 104 of them completed the course with a positive final mark. The forgetting model was implemented in 2007 both in self-tests and lab experiments. The students accepted it quickly.

In addition to the states exposed in the assignments sheet (Figure 2, see page 21), they could also view the prediction graphs. Timed activities (pre-registered class tests) were made available only if all preconditions were met by that time (Figure 52).

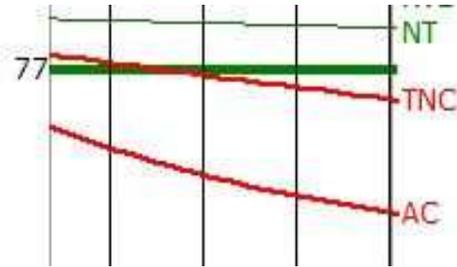


Figure 52 Assignment TNC will fall to the lower threshold

This caused additional pressure on the students – they had to return to the assignments with a positive outcome, but a negative prediction was made (Figure 53).

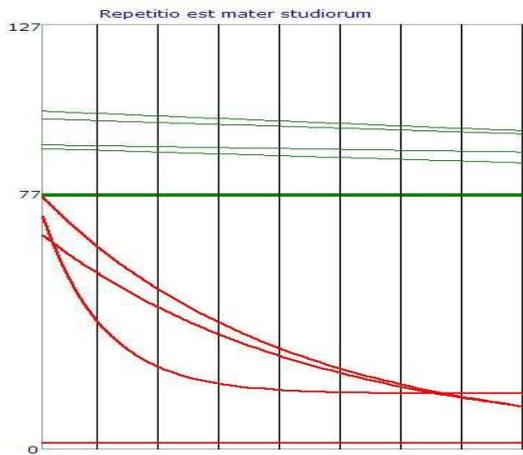


Figure 53 Prediction curve shown to the students

There were 12 self-tests implemented as multiple choice tests where a student had to mark which of four cases were equivalent to the prototype with respect to some parameters (e.g. the same current or voltage, the equivalent circuit, the frequency response, etc.). The correct answer might be any of the 16 cases, from no match to all 4 matches. The total number of attempts made by 125 students was 39,217 or 31.4 attempts per student and test. The number of attempts per student was varying from 1 to 1398.

If we consider the tests started from the levels equal or higher than the threshold, the total number of attempts was 12,128 varying from 1 to 659. This indicates that most of attempts were used to get into the positive region (≥ 77). 8 students out of 125 did not reach the threshold at all.

A year before, more students made only 24,666 attempts totally, and 9953 attempts were made at the levels higher or equal to 77. The increase for about 50% in those numbers in 2007 was predominantly caused by introducing the forgetting model.

The number of attempts and the final level were not correlated at all ($r=0.01$) which was demonstrated by the phenomenon that had been observed previously: the majority of the students with good learning results continued improving even when they had reached the highest states.

The histogram showing the number of assignments activated at the levels higher or equal to the threshold is shown in Figure 54.

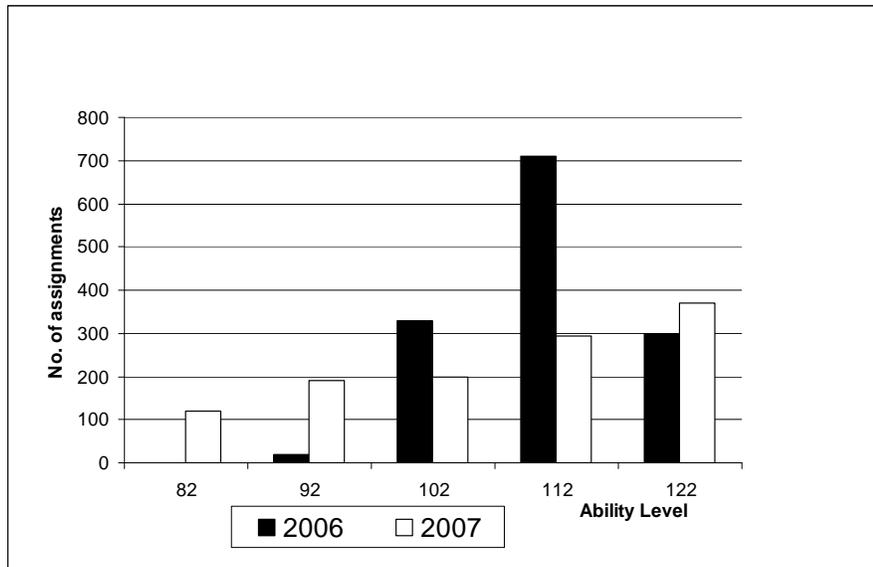


Figure 54 Number of assignments activated at higher levels

The number of attempts at all levels is shown in Figure 55. The large number of attempts at lower levels was the result of applying the forgetting mechanism as the students fell back to the lower levels frequently.

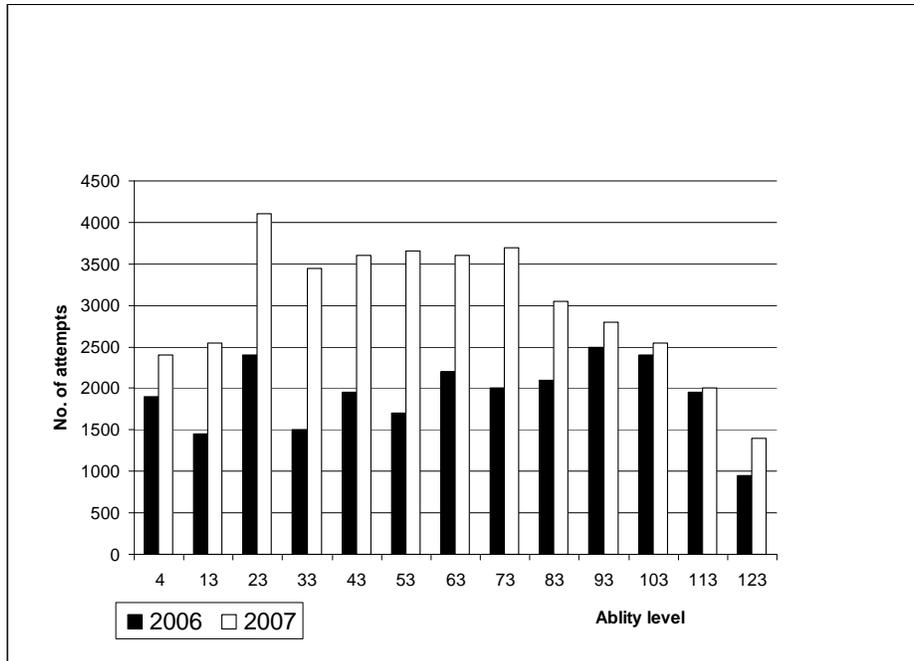


Figure 55 Number of attempts per ability levels

There were minor differences at higher levels confirming that the students who had reached that region were confident despite the forgetting mechanism was implemented. The total number of sessions was 4946 per 1264 assignments performed by the students, that was approximately 4 sessions in average.

Figure 56 demonstrates the state dynamics including two sessions and the prediction process including the time constant calculation. The data analysis confirmed a wide diversity of students in the sense of efforts made in carrying out the assignments (the amount of attempts differed for at least 4–5 times).

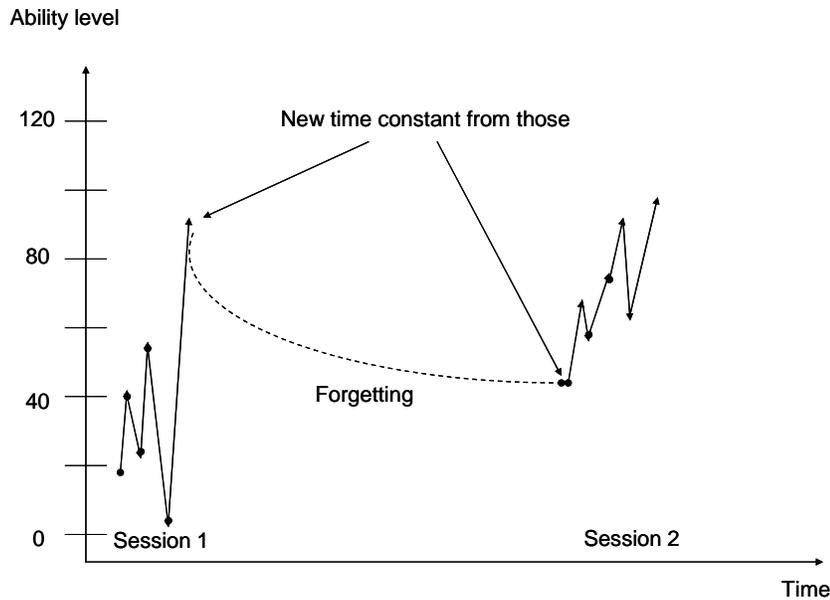


Figure 56 Session results, forgetting process and items for a new time constant

In the following, lab statistics are analysed. Totally, 117 students made 26,613 attempts in 2,867 sessions (9.3 acts per session). The number of attempts per assignment varied from few (2–3) to several hundreds. A large number of attempts here demonstrates the guessing behaviour of the students as the number of different experiments was rather limited (197) if compared with the self-tests (thousands). The number of attempts per assignment should be multiplied by the number of kits (25) that makes about 3000 different experiments in total; however, dividing this by the number of labs (9), we have only about 400 cases per assignment in average.

The guessing behaviour of the students should be considered remarkable. The results were evaluated on the wrong-to-correct scale instead of using a continuous scale. No effective way to avoid such behaviour has been found so far. Probably, further research and more data are needed as it was with self-tests. However, it is difficult to compare those results with the data of the previous years due to the substantial change of the conditions of the learning environment.

The number of incorrect results obtained by the students was remarkably high. The numbers of lab experiments at all levels are shown in Figure 57. The extremely high number at low levels 0...7 is a clear indicator of how difficult is to reach the proper experiment techniques and the ability to validate the measurement results.

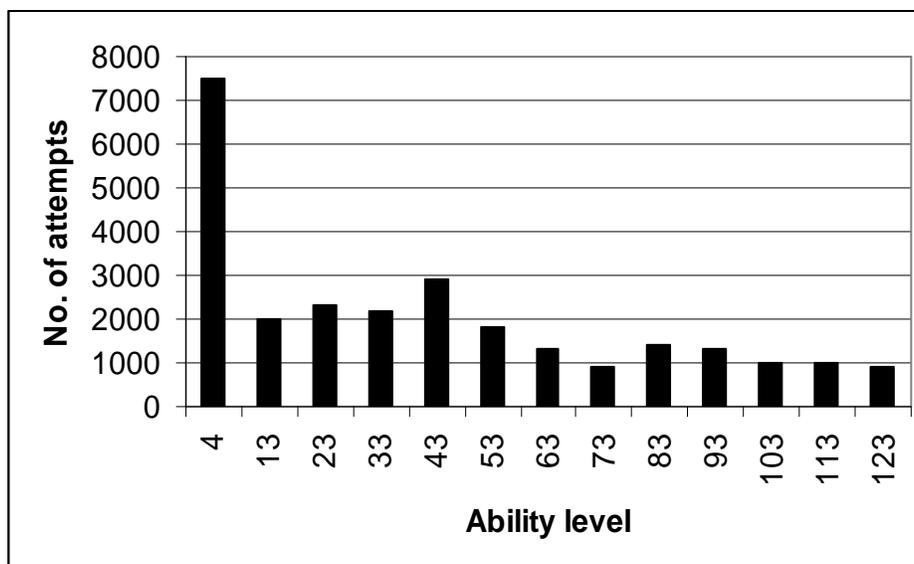


Figure 57 Lab experiments at different levels

Until 2007, the class-tests included only theoretical tasks. Before the state model was applied, the percentage of unsuccessful tests was at the level about 23% (over the years). Applying the state mechanism increased this percentage to 40. In 2007, lab experiments were also included and class-tests were not divided into the groups of assignments any more. This made impossible to compare the numbers of the test actions taken. The total number of the test actions increased by 50% (from 750 to 1100). The distribution of attempts at the task levels is shown in Figure 58. In Figure 57, a strong similarity with the lab statistics could be observed. This can be explained by the inclusion of the lab experiments into the tests proved by the number of tasks: experiments – 7214 (57%), theoretical tasks – 5382 (42%). At the same time, there are 9 experiment topics and 12 theoretical topics that means the following average values: 802 for experiments and 448 for theoretical tasks. *Those results confirm that the goal has been achieved – to stress on students’ practical abilities.*

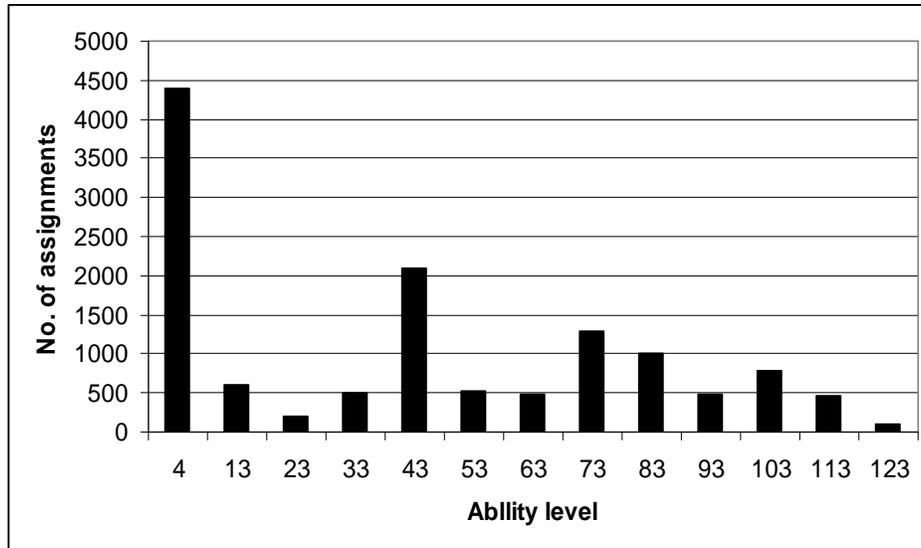


Figure 58 Class test experiments at different ability levels

The main goal of applying the forgetting model is to achieve the high quality of a long-term memory. A large number of attempts is related partially to using of a short-term memory (approximately 30 seconds). To suppress this, individual timing parameters were introduced into the evaluation procedure: the quick answers changed the state only slightly. The analysis of the log files shows clearly that in order to avoid the short-term memory problems, some timing should be used in both task selection and evaluation. This means that every task should be assigned both a difficulty level and some timing conditions.

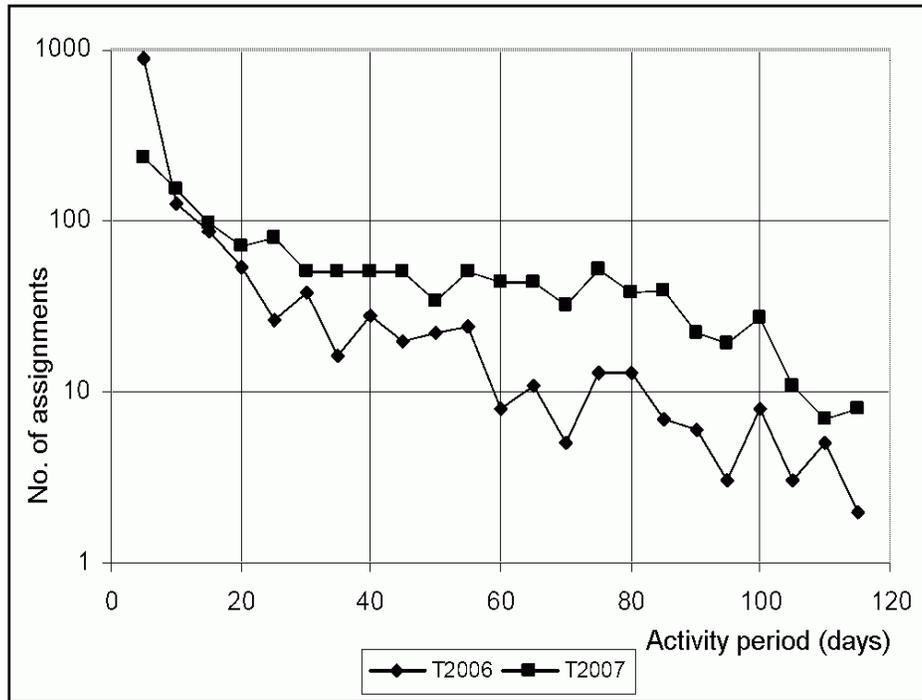


Figure 59 Number of actions active in different time periods

This would be done during the next correction session usually done once or twice a year. The final mark and the number of lab experiments are not correlated ($R=0.12$). It was remarkable that those who got the lowest mark used only the two-thirds of actions done by the students who had obtained higher marks (200 vs. 300). The time constants fixed finally by the end of a semester vary from the dozens of days to thousands (comparable with the values in [82]). The prediction of the average state for December 31, 2008 was 106, that was higher by 29 than the threshold value 77.

There was assumed that applying the forgetting machine would increase the time intervals during which the assignment was active (forced repetitions). This effect was achieved as seen from Figure 59 where the number of assignments versus the activity period (days) is shown. Very short activity periods had decreased dramatically (4 times for the periods up to 5 days) as the number of longer intervals had almost doubled. The effect of the forgetting model is demonstrated in Figure 60 and Figure 61 where 2 graphs related to the same assignment are presented from 2006 and from 2007 respectively.

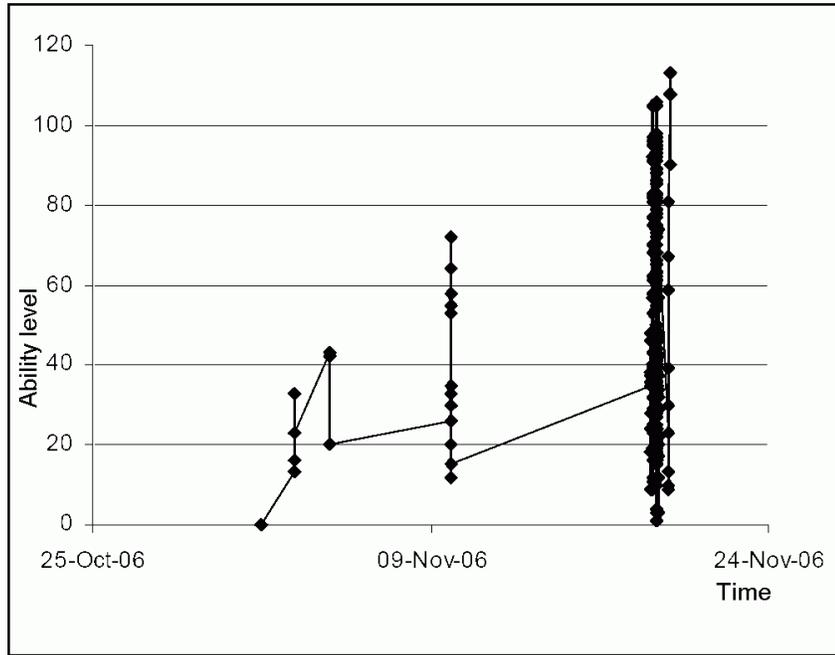


Figure 60 History of one assignment in 2006

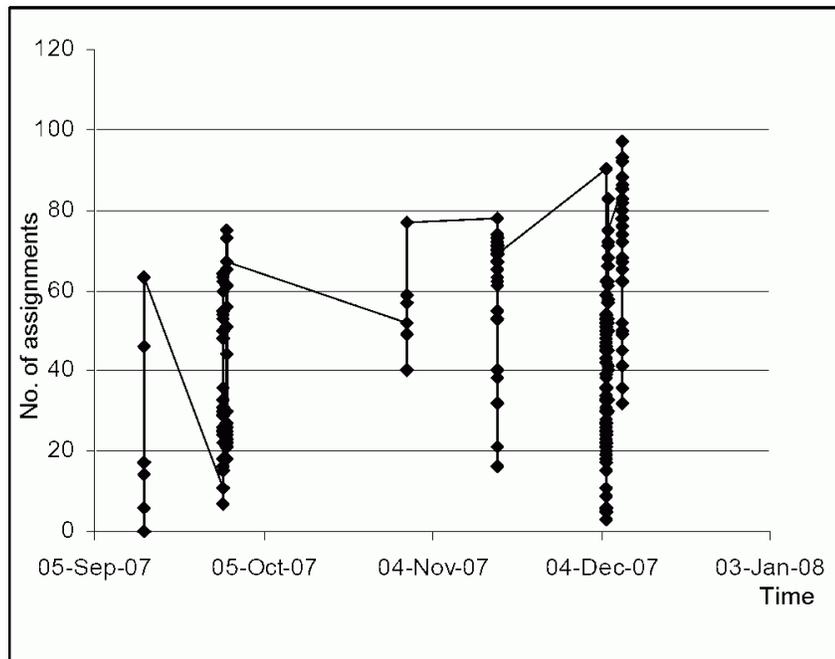


Figure 61 History of one assignment in 2007

Also, the forgetting model helped to decide on what topic to work – this claim was supported by 75% of the students. At the same time, 30% of the students claimed that the model showed faster forgetting than they had assumed. However, it was not fully supported by an independent data analysis, and probably the overestimation of forgetting caused more emotional reaction than the underestimation. If forgetting is assumed to be slow, then the system does not propose repetition and this has certain psychological effect.

6. Conclusions

In this chapter, the overview of the development of the interactive learning environment and the mobile laboratory equipment is presented. Also, the contributions of this dissertation are summarised and future aims are determined.

6.1 Overview

The creation of the web-based learning environment was started in the early 2000s in the Department of Computer Control at TUT and its development would be continued.

Finally, the following conclusions can be formulated.

1. As compared to the lab equipment used previously, and according to the analysis of students' behaviour, HomeLabKits appeared to be efficient in expanding students' opportunities to enlarge their knowledge about electrical measurements, analysing the results and understanding the relationship between theory and reality. The developed mobile equipment provides students better conditions to invest their learning resources.

2. On the base of the HomeLabKit and the related software, it is easy to create different versions of labs. The underlying idea of the learning environment is compiling courses from a large field of components (incl. static materials, tests, home and class works, labs); HomeLabKits support implementing this idea in the area of practical works.

3. The use of HomeLabKits can be extended to other courses and could be a part of labs even in the courses where distant and in-site labs are applied because of the limited cost, weight and complexity of the equipment.

4. The HomeLabKit and the field of competences can also be used at schools.

5. The quantity of labs can be increased with the developed laboratory equipment and software. In order to provide a variety in the time and place for conducting labs, a part of them could have been undertaken at home.

6. Lab experiments are integrated into the interactive learning environment along with other components. Thus, more numerous and detailed experiments can be embedded into the logical structure of assignments. It follows that instead of 0.1...0.3cu that are now assigned to labs, experiments will be evaluated together with other activities, and as in tests, unsuccessful

experiments are to be repeated until correct results will be obtained.

7. The developed interactive learning environment provides the immediate feedback to students by collecting and analysing the lab data and guiding students to appropriate study materials. The data can be collected and used in the future in order to improve and simplify the learning process, also to make the development more comfortable for students.

8. The main aim of applying the forgetting model is to achieve the high quality of a long-term memory. According to the data logs, the students had to return to the assignments with a positive outcome frequently and the number of attempts made at a low level in labs increased significantly. The use of the student's memory model decreases the amount of temporary skills. Besides, the forgetting model supports students in deciding which topic needs additional learning.

6.2 Contributions

The contributions of this dissertation can be summarised as follows.

1. The new types of laboratory assignments and the extraction process of results and competencies were created.

2. Flexible, changeable contents of the laboratories, with allocation of competencies and credit units on different parts of the subject were created. Competence-based simple lab experiments were introduced instead of traditional laboratory tests. According to the number of the labs and compared with the corresponding results of the traditional form of lab, the competence-based simple lab experiments reduced remarkably the amount of information acquired. Thus, the total number of individual laboratory tasks increased significantly as compared to the number of the results in 2006.

3. The student's memory model was introduced. The model simulates the behaviour of a human memory, namely forgetting which occurs with the length of the time elapsed, and highlights possible shortcomings in the acquired knowledge.

4. The HomeLabKit – a small mobile box containing all the necessary laboratory equipment to perform the practical work of the specific subjects – was developed. The HomeLabKit is designed in order to meet the criteria of simplicity and low cost. The greatest advantages of the HomeLabKit could be considered mobility, time and place independence. It also supports personalising the learning process. In addition to the HomeLabKit, also a computer, the Internet and a power network are required.

5. The environment was analysed and the arguments characterising the student's behaviour were formulated. The results can be applied in further work for development of complementing the student's behaviour model.

6.3 Future goals

The main aims for the future are the following.

1. Introducing the next, third generation of the HomeLabKit. The basic ideas for the further development are to use interactive and on-line programmed devices. The main benefit is to produce a large quantity of similar devices at a low price preferably and reprogram them before the next implementation. In order to simplify management of the mobile lab equipment, there is an idea to use RFID tags for identifying devices. To separate electric circuits and for safety in communications between devices Bluetooth is considered to replace USB (if possible).

2. Developing the competence-based interactive learning environment.

3. The results of the current thesis are the great source for implementing the overall student's behaviour model.

The author has already started with realising the aforelisted aims.

7. References

- [1] Higgs, B., McCarthy, M. Active learning: From lecture theatre to field-work. – *Emerging Issues in the Practice of University Learning and Teaching*. / eds G. O’Neill, S. Moore, B. McMullin. Dublin: AISHE, 2005.
- [2] Splitt, F. G. The challenge to change: on realizing the new paradigm for engineering education. – *J. Eng. Educ.*, 2003, 92 (2), 181–187.
- [3] Marozas, V., Dumbrava, V. Motivating the Students to Study the Basics of Digital Signal Processing by Using Virtual Learning Environment. – *Electronics and Electrical Engineering*, 2010, 6 (102).
- [4] Nichols, M. E- Learning in Context. [WWW] <http://akoaootearoa.ac.nz/sites/default/files/ng/group-661/n877-1---e-learning-in-context.pdf> (25.01.2010)
- [5] Strazds, A. M-learning evaluation – a multi-tasking approach. – *Conference on Interactive Mobile and Computer Aided Learning (IMCL 2006)*, Amman, Jordan, April 19–21, 2006. Kassel University Press [CD-ROM]
- [6] Brabazon, T. Mobile Learning: the iPodification of Universities. – Academic articles Brabazon.net [WWW] <http://brabazon.net/journalarticles> (26.01.2010)
- [7] Georgouli, K., Skalkidis, I., Guerreiro, P. A framework for adopting LMS to introduce e-learning in a traditional course. – *Educational Technology & Society*, 2008, 11 (2), 227–240.
- [8] Felder, R. M., Silverman, L. K. Learning and teaching styles in engineering education. – *J. Eng. Educ.*, 1988, 78 (7), 674–681.
- [9] Bonwell, C. C., Eison, J. A. Active learning: Creating excitement in the classroom. Washington, DC: George Washington University, ASHE-ERIC Higher Educ. Rep., 1991.
- [10] McKeachie, W. J. Teaching tips: Strategies, research, and theory for college and university teachers. 9th ed. Lexington, MA: D. C. Heath, 1994.
- [11] Simpson, T. W. Experiences with a hands-on activity to contrast craft production and mass production in the classroom. – *J. Eng. Educ.*, 2003, 19 (2), 297–304.
- [12] Lyublinskaya, I., Ryzhik, V. Interactive geometry labs – combining the US and Russian approaches to teaching geometry, – *Int. J. Cont. Eng. Educ. Life Long Learn*, 2008, 18 (5), 598–618.
- [13] Krivickas, R. V., Krivickas, J. Laboratory instruction in engineering education. – *Global J. Eng. Educ.*, 2007, 11 (2), 191–196.
- [14] Magdalena, R., Serrano, A. J., Martin-Guerrero, J. D., Rosado, A.,

- Martinez, M. A teaching laboratory in analog electronics: Changes to address the Bologna requirements. – *IEEE Trans. Educ.*, 2008, 51 (4), 456–460.
- [15] Prince, M. Does active learning work? A review of the research. – *J. Eng. Educ.*, 2004, 93 (3), 223–231.
- [16] Krouk, B. I., Zhuravleva, O. B. Dynamic Training Elements in a Circuit Theory Course to Implement a Self-Directed Learning Process. – *Education, IEEE Transactions on Education*, 2009, 52 (3), 394–399.
- [17] Savander-Ranne, C., Lunden, O.-P., Kolari, S. An Alternative Teaching Method for Electrical Engineering Courses. – *Education, IEEE Transactions on Education*, 2008, 51 (4), 423–431.
- [18] Allinson, C. W., Hayes, J. Cross-national differences in cognitive style: Implications for management. – *Int. J. Hum. Resource Manage*, 2000, 11, 161–170.
- [19] Hewijn Christine Jiau, Jinghong Cox Chen and Kou Feng Ssu. Enchanting self-motivation in learning programming using game based simulation and metrics. – *IEEE Transactions on Education*, 2009, 52(4), 555–562.
- [20] Vicent, L., Àvila, X., Anguera, J., Badia, D., Montero, J. Do Multimedia Contents increase the effectiveness of learning? – *IEEE Frontiers in Education Conference, 2006, San Diego (USA)*. San Diego, USA: FIE, 2006.
- [21] Rokk, I., Kulmar, M., Ots, A., Lossmann, E. Experiences of Teaching Complicated Undergraduate Course for Large Number of Students in the Tallinn University of Technology. – *Electronics and Electrical Engineering*, 2010, 6 (102).
- [22] Michell, J., Canavan, B., Smith, J. Problem based learning in communication systems: Student perceptions and achievement. – *IEEE Transactions on Education*, 2009, 53 (4), 587–594.
- [23] Hussein, B. A., Nyseth, K. A method for learning in project management. – *New Approaches on Learning, Studying and Teaching – 9th International Workshop on Experimental Interactive Learning in Industrial Management, June 5–7, 2005, Espoo, Finland*.
- [24] Castles, R. T., Zephirin, T., Lohani, V. K., Kachroo, P. Design and Implementation of a Mechatronics Learning Module in a Large First-Semester Engineering Course. – *IEEE Transactions on Education*, 2010, 53 (3), 445–454.
- [25] Saavedra Montes, A. J., Botero Castro, H. A., Hernandez Riveros, J. A. How to motivate students to work in the laboratory: A new approach for an electrical machines laboratory. – *IEEE Transactions on Education*, 2010, 53 (3), 490–496.
- [26] Kukk, V. Analysis of Experience: Fully Web Based Introductory Course in Electrical Engineering. – *Proceedings of the 1st International Workshop on e-learning and Virtual and Remote Laboratories, Setubal, Portugal, August 24–25, 2004, 111–118*.
- [27] Cox, D., Meric, Z., Bartz, R., Ctistis, Ch. Complementary Simulation and

- Remote Laboratory Experiences to Hands-on Control Systems Curriculum. – *International Conference on Engineering Education, ICEE, Gliwice, Poland, July 18–22, 2010.*
- [28] Kozick, R. J., Crane, C. C. An integrated environment for modeling, simulation, digital signal processing and control. – *IEEE Transactions on Education*, 1996, 39 (2), 114–119.
- [29] Robinette, M. F., Manseur, R. Robot-Draw, an Internet-based visualisation tool for robotics education. – *IEEE Transactions on Education*, 2001, 44 (1), 29–34.
- [30] Billard, E. A., Riedmiller, A. E. Laboratory exercises using a graphical user interface to a queuing simulator. – *IEEE Transactions on Education*, 1997, 40 (2), 154–157.
- [31] Ferreira, G. S., Zapelini, W. B. Analysis and comparison of educational resources in an undergraduate course in Electronics. – *International Computer Aided Learning Conference, Villach, Austria, September 27–29, 2006, 13.*
- [32] Machotka, J., Nedic, Z. Remote experiments in engineering undergraduate programs. – *International Computer Aided Learning Conference, Villach, Austria, September 27–29, 2006, 13.*
- [33] Krivickas, R. V., Krivickas, J. Laboratory instruction in engineering education. – *11th Baltic Region Seminar on Engineering Education, Tallinn, Estonia, June 18–20, 2007: Seminar Proceedings.* Clayton: UNESCO International Centre for Engineering Education (UICEE), 2007, 161–164.
- [34] Friesel, A. Motivating students to study the basics of electronic engineering in the world full of electronics. – *EAEIE Annual Conference, Valencia, June 22–24, 2009, 1–5.*
- [35] Consonni, D., Seabra, A. C. A modern approach to teaching basic experimental electricity and electronics. – *IEEE Transactions on Education*, 2001, 44 (1), 5–15.
- [36] Documentations of HomeLabKit projects. [WWW] <http://isc.dcc.ttu.ee/HDLK> (10.12.2009)
- [37] Jegelevičius, D., Pagodinas, D., Dumbrava, V. Laboratory Experiments in Circuit Theory: Link between Theoretical Concepts and Practical Examples. – *Electronics and Electrical Engineering*, 2010, 6 (102), 107–110.
- [38] Marozas, V., Jurkonis, R., Lukoševičius, A. Development of virtual and remote lab experimentation system for electronics engineering. – *Electronics and Electrical Engineering*, 2008, 7 (87), 41–44.
- [39] Sveikata, J. A., Dekeris, B. Changes of equipment and topics in laboratory of circuit theory. – *Innovation in Education for Electrical and Information Engineering 2008 [Elektroninis išteklis], June 29 – July 2 2008, Tallinn, Estonia – Proceedings of the 19th EAEIE Annual Conference.* Tallinn: European Association for Education in Electrical and Information Engineering, 2008, 1–4.
- [40] Grega, W., Papadourakis, G. Mobile laboratory for training in network

- technologies. – *Electronics and Electrical Engineering*, 2010, 6.
- [41] Margalef, J., Vicent, L., Senmartí, X., Bou, G., Anguera, J. The teaching of electronics engineering: Guidelines for the design of training in and out of the classroom setting. – *37th ASEE/IEEE Frontiers in Education Conference, IEEE, Milwaukee, WI, USA, October 10–13, 2007, S3G-10*.
- [42] Bofahl, P., Chouikha, M. Integrating lectures and labs using the mobile studio. – *International Conference on Engineering Education ICEE 2010, Gliwice, Poland, July 18–22, 2010*.
- [43] Shyr, W.-J. Integrating laboratory activity into a junior high school classroom. – *IEEE Transactions on Education*, 2010, 53 (1), 32–37.
- [44] Jaanus, M. Sidulabori uuendamine (Development of circuits lab). Bachelor thesis. Tallinn: TUT, 2000.
- [45] Jaanus, M. Sidulabori arendamine (Enhancement of circuits lab). Master thesis. Tallinn: TUT, 2003.
- [46] Plastic box 35x90x110 mm. [WWW] <http://www.elfaelektronika.ee/artnr/24-575-12/plastic-box-35x90x110-mm-> (18.01.2010)
- [47] 8-bit Microcontroller with 2K Bytes Flash ATtiny26 ATtiny26L. [WWW] <http://www.atmel.com/atmel/acrobat/doc1477.pdf> (03.01.2010)
- [48] Sullin, A. Kodulabori vahelduvvooluallika-ostsillooskoobi disain (Design of AC generator and scope for HomeLabKit). Master thesis. Tallinn: TUT, 2007.
- [49] Atmel Products – AVR Solutions – ATmega88. [WWW] http://www.atmel.com/dyn/products/product_card_v2.asp?part_id=3302 (03.01.2010)
- [50] Van der Broeck, H. W., Skudelny, H. C. Analysis and realization a pulse width modulator based on a voltage space vector. – *IEEE Trans. Industry Applications*, 1988, IA-24 (1), 142–150.
- [51] Grant, D. A., Stevens, M., Houldsworth, J. A. The effect of word length on the harmonic content of microprocessor-based waveform generators. – *IEEE Trans. Industry Applications*, 1985, IA-21 (1), 218–225.
- [52] Horowitz, P., Hill, W. The art of Electronics. Second edition. Cambridge University Press, 1998.
- [53] TL071 Operational amplifier datasheet. [WWW] http://www.datasheetcatalog.com/datasheets_pdf/T/L/0/7/TL071.shtml (12.10.2009)
- [54] Carlson, A. B. Circuits: Engineering Concepts and Analysis of Linear Electric Circuits. Stamford, CT: Books Cole, 2000.
- [55] Kangur, O., Ratassepp, J. Ahelate teooria 1. Laboratoorsed tööd. Tallinn, 1989.
- [56] Kangur, O., Ratassepp, J. Ahelate teooria 2. Laboratoorsed tööd. Tallinn, 1989.
- [57] Lux tools. [WWW] <http://www.emil-lux.de/> (27.04.2010)
- [58] Wozniak, P. Effective learning: Twenty rules of formulating knowledge in

- learning. [WWW] <http://www.supermemo.com/articles/20rules.htm> (25.04.2010)
- [59] Carvalho, C., Salonen, J., Bjorn, K., Knoeaert, S., Van Steerberge, R., Scoofs, L., Rugelij, J., Marzo, J. L. European Study Programme for Advanced Networking Technologies. – *Electronics and Electrical Engineering*, 2010, 6 (102), 31–34.
- [60] Lee Chye Seng, Tan Tiong Hok. Humanizing E-Learning. – *Proceedings of the 2003 International Conference on Cyberworlds (CW'03)*. IEEE Computer Society Washington, DC, USA, 2003, 418–422
- [61] Competences in Organizational E-Learning: Concepts and Tools. / ed. Sicila, M.-A. Hershey, Pennsylvania: Information Science Publishing, 2006.
- [62] Consulting, O. Competency Data for Training Automation, 2005. [WWW] <http://www.ostyn.com/standardswork/competency/CompetencyDataForTrainingAutomation.htm> (03.09.2010)
- [63] Paquette, G. Educational Modeling Languages, from an Instructional Engineering Perspective. Center for Interuniversity Research on Telelearning Applications, Université du Québec, 2001
- [64] Vesapuisto, M., Korpinen, L., Koskiranta, M., Lehtelä, R., Vekara, T. The students' feedback on WWW-course "Electricity, Electronics and Environment". – *Electronics and Electrical Engineering*, 2010, 6 (102), 99–102.
- [65] Hölbl, M., Welzer, T. Students' feedback and communication habits using Moodle. – *Electronics and Electrical Engineering*, 2010, 6 (102), 63–66.
- [66] Getty, J. C. Assessing Inquiry Learning in a Circuits/Electronics Course. – *Proceedings of the 39th IEEE International Conference on Frontiers in Education Conference, 2009*. San Antonio, TX: IEEE Press, 2009, 817–822.
- [67] Thomas, L., Ratcliffe, M., Woodbury, J., Jarman, E. Learning styles and performance in the introductory programming sequence. – *Proc. 33rd ACM Tech. Symp. Computer Science Education (SIGCSE)*. 2002, 33.
- [68] Sanders, D. A., Suso, J. B. Inferring learning style from the way students interact with a computer user interface and the WWW. – *IEEE Transactions on Education*, 2010, 53 (4), 613–620.
- [69] Bergasa-Suso, J., Sanders, D. A., Tewkesbury, G. E. Intelligent browser based systems to assist Internet users. – *IEEE Transactions on Education*, 2005, 48, 580–585.
- [70] Strazds, A., Kapenieks, A. Automated satisfaction measurement for e-learning target group identification. Florianopolis, Brazil: ICBL, 2007.
- [71] Kybartaitė, A. Impact of modern educational technologies on learning outcomes application for e-learning in biomedical engineering. PhD. Thesis, Tampere: Tampere University of Technology, 2010.
- [72] Reilly, R. Virtual laboratories: Enhancing deep learning in model-based knowledge domains. – *IEEE Transactions on Education*, 2008, 51 (1), 1.
- [73] Barajas, M., Scheuermann, F., Kikis-Papadakis, K., Greece, H. Is the Role

- of the Teacher as the “Knowledge Authority” in Danger in an ICT-Learning Setting? [WWW]
http://www.elearningeuropa.info/directory/index.php?doc_id=580&doclng=6&page=doc (03.09.2010)
- [74] Gray, D. E., Ryan, M., Coulon, A. The training of teachers and trainers: Innovative practices, skills and competencies in the use of e-learning. – *European Journal of Open, Distance and e-Learning*, 2004/ II. [Online] (09.09.2010)
- [75] Díaz, L. A., Entonado, F. B. Are the functions of teachers in e-learning and face-to-face learning environments really different? – *Educational Technology & Society*, 2009, 12 (4), 331–343.
- [76] Entonado, F. B., Díaz, L. A. A Training Proposal for e-Learning Teachers. Universidad Extremadura, Badajoz, Spain. [WWW]
http://www.eurodl.org/materials/contrib/2006/Blazquez_and_Alonso.htm (10.09.2010)
- [77] Ebbinghaus, H. Über das Gedächtnis. Untersuchungen zur experimentellen Psychologie. Leipzig, Germany: Duncker & Humblot, 1885. / In English: Memory: A Contribution to Experimental Psychology. Hermann Ebbinghaus. Translated by H. A. Ruger, C. E. Bussenius. New York: Teachers College, Columbia University, 1913. [WWW]
<http://psychclassics.yorku.ca/Ebbinghaus/index.htm> (10.09.2010)
- [78] Pavlik, P. I., Anderson, J. R. Practice and forgetting effects on vocabulary memory: An activation-based model of the spacing effect. – *Cognitive Science*, 2005, 29, 559–586.
- [79] Moridis, C. N., Economides, A. A. Mood recognition during online self-assessment test. – *IEEE Transactions on Learning Technologies*, 2009, 2 (1), 50–61.
- [80] Tu, L. Y., Hsu, W. L., Wu, S. H. A cognitive student model – an ontological approach. – *Proc ICCE'02*, 2002, 111–112.
- [81] Jeremic Z., Devedzic, V. Design Pattern ITS: Student Model Implementation. – *Proc ICALT'04*, 2004, 864–865.
- [82] Sviridov, A. P. Modelling of the knowledge dynamics of students or employees. – *Proc ESM 2003*, 485–490.

8. Publications

8.1 Publications related to this thesis

1. Jaanus, M., Hein, N., Kukk V., Sullin, A. Home Lab Kits for Introductory Course in Electrical Engineering. EUROCON 2007. – *The International Conference on “Computer as a Tool”, Warsaw, Poland, September 9–12, 2007*, 2676–2679.
2. Kukk V., Jaanus, M. Student forgetting model: practical experience. – *EAEIE 2008 proceedings CD-ROM: 19th EAEIE Annual Conference, Tallinn, Estonia, June 29 – July 2, 2008*, 112–117.
3. Shvets, O., Kukk, V., Jaanus M., Umbleja, K. Home and remote laboratories – development of web-based practical works for higher and vocational education. – *Journal of International Scientific Publications: Materials, Methods & Technologies*, 2009, 3, 323–335.
4. Kukk, V., Jaanus, M., Umbleja K., Shvets, O. Developing integrated learning environment – analysis. – *International Conference on Engineering Education ICEE 2010, Gliwice, Poland, July 18–22, 2010*.
5. Shvets, O., Kukk, V., Jaanus M., Umbleja, K. Remote laboratories and methods of their application in study process. – *Journal of International Scientific Publications: Materials, Methods & Technologies*, 2010, 4 (2), 60–67.
6. Jaanus, M., Kukk V., Umbleja, K. Integrating labs into learning environment. – *Electronics and Electrical Engineering*, 2010, 6, 27–30.

8.2 Other publications related to scientific research

1. Jaanus, M., Seiman, A., Vaher, M., Makarõtcheva, N., Kuuskmäe, E., Kaljurand, M. Portable capillary electrophoresis instrument. – *Abstract Book and Program: 5th Conference on Separation and Related Techniques by Nordic Separation Science Society, Estonia, 2009*, 59. / eds M. Borissova, M. Vaher. Tallinn: Tallinn Technical University Press, 2009.
2. Helmja, K., Borissova, M., Knjazeva, T., Jaanus, M., Muinasmaa, U., Kaljurand M., Vaher, M. Fraction collection in capillary electrophoresis for various stand-alone mass spectrometers. – *Journal of Chromatography A*, 2009, 1216 (17), 3666–3673.
3. Gorbatsova, J., Jaanus, M., Kaljurand, M. Digital microfluidic sampler for a portable capillary electropherograph. – *Analytical Chemistry*, 2009, 81 (20), 8590–8595.
4. Seiman, A., Jaanus, M., Vaher, M., Kaljurand, M. A portable capillary electropherograph equipped with a cross-sampler and a contactless-conductivity detector for the detection of the degradation products of chemical warfare agents in soil extracts. – *Electrophoresis*, 2009, 30, 507–514.

9. Appendices

9.1 Examples of lab processing scripts

9.1.1 Resistance measurement

In the following, some of lab processing scripts are described. In the current task the resistance of a resistor should be measured (Figure 62).

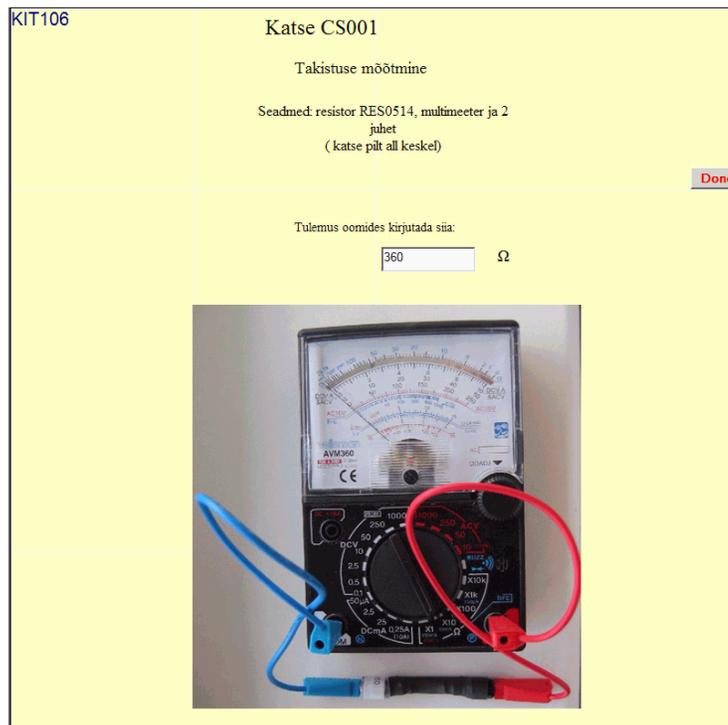


Figure 62 Screenshot of a resistance measurement task

```
Dim R0,X,result2,errate,unit,Temp ` Variables
R0=VAD("#R#/R") ` Get estimated value from database
` R - result, entered by student
` S2E - subroutine for adding or subtracting value of
competences . Example S2E, competence, value
```

```

If Trim(R)="" Then
  S2E 140,-1 ` if result is empty, do not process result ` and
  give result as "easy pass"
End If
X=CSng(R) ` make numeric variable

`----- Unit check-----
`resistance is expected in ohms.
result2=1 ` assign value for competence "measurement unit"
unit=1
unit2=1000
` resistance of resistors in this task is between 100 ohm and 1
kilo-ohm. If value is lower than 1, answer is given in kilo-ohms.
IF X<1 then
result2=-1 ` assign new value for competence "measurement unit"
X=X*unit2 ` also result is corrected for processing
End if
S2E 237,result2 ` set value of competence
` measurement check
` AbsDeadZone - function for calculating multimeter accuracy
Parameters: measured difference, allowed difference
Temp=AbsDeadZone(X-R0,R0*0.03)
Temp=Temp/R0
If Temp=0.0 Then
  S2E 140,1 ` measured correctly
ElseIf Temp<=0.20 Then
  S2E 140,(0.20-Temp)/0.20 ` measurement error/unsuccessful zero
  adjustment.
ElseIf Temp>0.20 Then `maybe wrong resistor ?
  S2E 140,-1
  S2E 150,-1 `Error of composing circuit

End If

```

9.1.2 Kirchhoff's current law

In the following, a task where currents must be measured using an analogue multimeter (Figure 63) is provided.

KIT360

Katse CS536

Kirchhoffi vooluseadus

Vooluseaduse test. Seadmed: voolallikas, resistorid R060 ja R061 ning multimeeter AVM360

Done

Mõõta vool I1 mA

Mõõta vool I2 mA

Mõõta vool I3 mA

Arvutada I1+I2+I3: mA

Figure 63 Screenshot of the task for the application of Kirchhoff's current law

```

Dim R1,R2, Res, X, Rin1, Rin2, EL, ML ` variables
R1=VAD("#R1#/R") ` get values of resistors from database
R2=VAD("#R2#/R")
` make numeric variables I1,I2;i3, I1I2I3 , entered data
I1=CSng(I1)
I2=CSng(I2)
I3=CSng(I3)
If I1I2I3="" Then
  I1I2I3=0
Else
  I1I2I3=CSng(I1I2I3)
End If
` Determine measurement range and internal resistance
` AVM360
If Abs(I2)<2.5 Then
  Rin1=100
  EL2=2.5*0.03
  ML=2.5*0.1
Else

```

```

Rin1=10
EL2=25*0.03
ML=25*0.1
End If
Calculating estimated values, considering internal resistance
K1=R2/(R1+Rin1+R2)
Res=(Abs(I1*K1+I2)-EL2)/ML
If Res<0.0 Then Res=0.0
Res=1.0-Res
If Res<-1 Then Res=-1
`set competences
T4=52 `current divider
T5=139 `Multimeter, DC current
T6=255` Measuring analog meter
Res1=Res
` S2E - subroutine for adding or subtracting value of
competences . Example S2E, competence, value
` calculate estimated currents and overset competence values if
needed
If Abs(I3)<2.5 Then
Rin1=100
EL3=2.5*0.03
ML=2.5*0.1
Else
Rin1=10
EL3=25*0.03
ML=25*0.1
End If
K2=R1/(R1+Rin2+R2)
Res=(Abs(I1*K2+I3)-EL3)/ML
If Res<0.0 Then Res=0.0
Res=1.0-Res
If Res<-1 Then Res=-1
Res=(Res+Res1)/2
S2E T4,Res
S2E T5,Res
S2E T6,Res
X=Abs(CSng(I1)+CSng(I2)+CSng(I3))

```

```

I=Abs(CSng(I1)-I1*K1-I1*K2)
T1=192 `Sum of incoming currents is zero
` using analogue meter a real sum of currents differs from zero
EL=EL2
If EL3>EL2 Then EL=EL3
Res=(Abs(X-I)-EL)/10
If Res<0.0 Then Res=0.0
Res=1.0-Res
If Res<-1 Then Res=-1
S2E T1,Res
` check calculation
If IsNumeric(I1I2I3) Then
Res=(Abs(I-I1I2I3)-EL)/10
If Res<0.0 Then Res=0.0
Res=1.0-Res
If Res<-1 Then Res=-1
Else
Res=-1
End If
T2=155 `Calculation
S2E T2,Res
` check polarity of results
T3=152 ` Current sign
If (Sgn(I1)*Sgn(I2))>0 OR (Sgn(I1)*Sgn(I3)>0) Then
S2E T3,-1
End If

```

9.1.3 AC measurements

In the following, the task magnitude and the phase transfer ratio is measured (Figure 64).

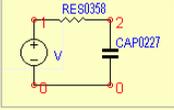
KIT322	<p>Katse CS054</p> <p>Faasorid: RC</p> <p>Leida ülekanne amplituud dB-des ja faasinäe kraadides</p> <p>Seadmed: ACSourceScope, RES0358 ja CAP0227</p> <p style="text-align: right;">Done</p>
	<p>Valida allikal sagedus 1470 Hz</p> <p>Mõõta pingeleekanne (väljund klemmid 2 ja 0) <input type="text" value="0.693"/></p> <p>Arvutada ülekanne detsibellides <input type="text" value="-3.185"/> dB</p> <p>Mõõta väljundpinge faasinäe sisendi suhtes <input type="text" value="-46"/> °</p> <p>Sisend (CH1): klemmid 1 ja 0</p> <p>Väljund (CH2): klemmid 2 ja 0</p> 

Figure 64 Assignment of AC measurements

```
dim t,faas,result ` variables

if V=0 then S2E 252,1 ` competence "easy pass"
` if result is zero give result as "easy pass"
`read values
faas=PHI
t=V

`compose circuit
if faas>0 and t>1 then
`if both phase >0 and transfer>1 then maybe mixed scope inputs
faas=-faas `correction and set competence
t=1/t
```

```

S2E 264,-1 ` composing circuit
else
S2E 264,1
end if
` in this circuit estimated phase is -45o. Since frequency is cut
frequency, the gain remains same if R and C are misplaced.
if faas>0 then ` set competence R C misplaced
faas=-faas
S2E 265,-1
else
S2E 265,1
end if
`Phase check,
faas=Abs(faas)
if faas<33 or faas>57 then
S2E 266,-1
else
S2E 266,1
end if
` transfer calculation check
if t>1 then
S2E 244,-1
t=1/t
else
S2E 244,1
`transfer value must be close to 0.71
if t>0.85 or t<0.5 then S2E 244,-1
end if
`decibels calculation check
result=1
Result=Result-(Abs(DB-dBlog(t)))
if result<-1 then result=-1
S2E 246,result' decibel calculation

```

9.2 List of lab competences for the subject “Circuits, systems, signals”

In the following, all competences supported by lab assignments created by the author of this dissertation are listed (as of February 15, 2011).

μ ; $\mu^*k=m$; $\mu/m=m$; $1/j=-j$; $1/kO=mS$; $1/m=k$; $2*PI$ ($w-f$) ; 3-pole equivalent circuit ; $A=S*V$; $A=V/O$; AC admittance, C ; AC admittance, L ; AC Current divider LR ; AC power ; AC scope- frequency set ; AC scope inputs ; AC voltage measurement ; Ammeter is short circuit ; Average PWL ; Average sine ; Average square ; $C=A*s$; $C=V*F$; Calculate average ; Calculation ; Calculation - decibels ; Calibration ; Capacitor at high () frequency ; Capacitor at low (0) frequency ; Capacitor energy $C*V^2$; Capacitor: current advances voltage by 90 deg ; Capacitors in parallel ; Capacitors in series ; Complex numbers: division ; Complex numbers: multiplication ; Compose circuit ; Composing circuit ; conductance ; conductance unit ; Conductance unit is S ; Current divider ; Current sign ; Current source and resistor in series ; Current source is open circuit ; Current unit ; dB/dec ; DC bridge ; DC transmittance, current ; DC transmittance, voltage ; Decibels ; Derivative: cosine ; Derivative: exp ; Derivative: sine ; Diode ; Diodes in series ; Driving-point admittance ; easy pass ; $F/s=S$; First order differential equation ; Forward bias ; Frequency of harmonic signal ; Frequency response, 1st order, amplitude ; Frequency response, 1st order, phase ; Frequency response, 2nd order, amplitude ; Frequency response, 2nd order, phase ; Frequency response, amplitude, CR ; Frequency response, amplitude, CR-CR ; Frequency response, amplitude, LR ; Frequency response, amplitude, LR-LR ; Frequency response, amplitude, RC ; Frequency response, amplitude, RL ; Frequency response, amplitude, RL-LR ; Frequency response, amplitude, R-RC ; Frequency response, constant, amplitude ; Frequency response, constant, phase ; Frequency response, phase, CR ; Frequency response, phase, CR-RC ; Frequency response, phase, LR-RL ; Frequency response, phase, RC ; Frequency response, phase, RC-CR ; Frequency response, phase, RC-RC ; Frequency response, phase, RL-RL ; Frequency response, phase, ; R-RC ; Frequency response, resonance, amplitude ; Frequency response, resonance, phase ; Frequency unit ; G ; $G=1/R$; $G=1/V$; $H/O=s$; High frequency equivalent ; $I=G*V$; $I=G*V$, directions ; $I=V/R$; $I1+I2=0$; Impedance LC parallel ; Impedance RC parallel ; Impulse response ; Incoming current equals to outgoing ; Inductor at high () frequency ; Inductor at low (0) frequency ; Inductor energy $L*I^2$; Inductor: voltage advances current by 90 deg ; Inductors in parallel ; Inductors in series ; Integral: cosine ; Integral: exp ; Integral: sine ; $j^2=-1$; k ; $k*p=n$; Laplace transform, 1st order ; Laplace transform, 2nd order ; Low frequency equivalent ; M ; m ; $M*\mu=1$; $m*k=1$;

$m \cdot m = \mu$; $m \cdot M = I$; $M \cdot n = m$; $M \cdot p = \mu$; $mA = V/kO$; Matrix: determinant ;
 Matrix: multiplication ; Measurement error accuracy ; Measurement: result
 and error accuracy ; Measuring amplitude ; Measuring analog meter ;
 Measuring average ; Measuring capacitance ; Measuring frequency ;
 Measuring inductance ; Measuring oscilloscope ; Measuring phase ;
 Measuring p-p ; Measuring resistance ; Measuring rms ; Measuring signal
 fronts ; Multimeter, AC voltage ; Multimeter, DC current ; Multimeter, DC
 voltage ; Multimeter, resistance ; Multipole, measure z driving point ;
 Multipole, measure z mutual ; Multipole, measure y driving-point ; Multipole,
 measure y mutual ; Mutual admittance ; $n \cdot k = \mu$; $n/\mu = m$; Negative resistance ;
 No Thevenin circuit for current source ; Node admittance matrix ; Node
 impedance matrix ; Norton circuit and internal resistance ; Norton circuit and
 open circuit voltage ; Norton circuit and resistor in series ; $O \cdot F = s$; OpAmp
 amplifier ; OpAmp Applications ; OpAmp INIC ; OpAmp integrator ; OpAmp,
 2-stage ; OpAmp, finite gain ; Open circuit equals zero current ; p ; Period of
 harmonic signal ; Period of sum of cosines ; Period of sum of sines ; Phacors:
 LC series ; Phase sign ; Phasor, admittance ; Phasor, impedance ; Phasors: LC
 parallel ; Phasors: RC parallel ; Phasors: RC series ; Phasors: RL parallel ;
 Phasors: RL series ; Prefix ; $Q = V \cdot C$; $R = 0$ is short circuit ; $R = 1/G$; R-C
 replaced /compose circuit ; Resistance unit ; Resistor; voltage and current are
 inphase ; Resistors in parallel ; Resistors in series ; Resonance frequency,
 parallel ; Resonance frequency, series ; Resonance, Q-factor ; RMS and power
 ; RMS sawtooth ; RMS: combined ; RMS: DC ; RMS: rectangular ; RMS: sine ;
 RMS: triangle ; Si diode forward approx 0.7V ; Signal flow graph, no loop ;
 Signal flow graph, one loop ; Signal flow graph, two loops ; Step response $r(0)$
 ; Step response $r(8)$; Step response: CR ; Step response: CR expression ; Step
 response: LR ; Step response: LR expression ; Step response: RC ; Step
 response: RC expression ; Step response: RCR ; Step response: RCR expression
 ; Step response: RL ; Step response: RL expression ; Step response: RLR ; Sum
 of incoming currents is zero ; Sum of outgoing currents is zero ; Zero current
 implies zero voltage ; Zero voltage implies zero current ; Thevenin circuit ;
 Thevenin circuit and open circuit voltage ; Thevenin circuit and resistor in
 parallel ; Thevenin circuit and resistor in series ; Thevenin circuit and short
 circuit current ; Time constant ; Time constant, RC ; Time constant, RL ;
 Transfer calculation ; Transfer function RC ; Transfer function RL ;
 Transmittance at frequency f ; Twopole, linear ; Twopole other port shorted
 $Y12Y21$; Twoport, ABCD ; Twoport, h input ; Twoport, h mutual ; Twoport, z
 input ; Twoport, z mutual ; Twoport, y input ; Twoport, y mutual ; Twoport:
 ABCD measurement ; Twoport: H measurement ; Twoport: measurement ;
 Twoport: Z measurement ; Twoport: Y measurement ; W ; $V \cdot mS = mA$;
 $W/AA = O$; $W/VV = S$; $W = A \cdot V$; $V = A/S$; $V = O \cdot A$; $V = R \cdot I$; $V = R \cdot I$, directions ;
 $V1:V2 = n1:n2$; $Wb = V \cdot s$; $V_o < 0$ and $I_s > 0$ means $R > 0$; $V_o > 0$ and $I_s < 0$ means
 $R > 0$; Voltage divider ; Voltage divider, loaded ; Voltage is difference of

potentials ; Voltage measurement ; Voltage sign ; Voltage source and resistor in parallel ; Voltage source and resistor in series ; Voltage source is short circuit ; Voltage sources in series ; Voltage sum in loop is zero ; Voltage unit ; Voltmeter and resistor in series ; Voltmeter is open circuit

ELULOOKIRJELDUS

1. Isikuandmed

Ees- ja perekonnanimi: Martin Jaanus
Sünniaeg ja -koht: 16. juuni 1977, Kohtla-Järve, Eesti
Kodakondsus: Eesti

2. Kontaktandmed

Aadress: Kütise 7-25, 76505 Saue, Harjumaa
Telefon: (+372) 5691 3193
E-posti aadress: martinj@ttu.ee

3. Hariduskäik

Õppeasutus (nimetus lõpetamise ajal)	Lõpetamise aeg	Haridus (eriala/kraad)
TTÜ	2003	Tehnikamagister
TTÜ	2000	Tehnikabakalaureus

4. Keelteoskus (alg-, kesk- või kõrgtase)

Keel	Tase
Eesti	Emakeel
Inglise	Keskase
Vene	Keskase

5. Teenistuskäik

Töötamise aeg	Tööandja nimetus	Ametikoht
2003 ...	Tallinna Tehnikaülikool	Assistent

6. Teadustegevus

„Arukad komponendid ja nende ühendamise probleemid”, 2003
„Analoogsidude analüüsi automatiseerimine”, 2001

7. Kaitstud lõputööd:
 - „Sidulabori arendamine”, 2003
 - „Sidulabori uuendamine”, 2000

8. Teadustöö põhisuunad
 - Kaug- ja kohtlaborite arendamine

9. Teised uurimisprojektid
 - Mõõteprotsesside automatiseerimine ja väljatöötamine TTÜ Keemia-instituudis

CURRICULUM VITAE

1. Personal data

Name: Martin Jaanus
Date and place of birth: 16th June 1977, Kohtla-Järve, Estonia

2. Contact information

Address: Kütise 7-25, Saue Town, Harju County,
Estonia
Phone: +(372) 5691 3193
E-mail: martinj@ttu.ee

3. Education

Educational institution	Graduation year	Education (field of study/degree)
Tallinn University of Technology	2003	Master of Science
Tallinn University of Technology	2000	Bachelor's degree

4. Language competence/skills (fluent, average, basic skills)

Language	Level
Estonian	Native
English	Average
Russian	Average

5. Professional Employment

Period	Organisation	Position
2003 ...	Tallinn University of Technology	Assistant

6. Scientific work

“Intelligent components and their integration problems”, 2003

“Automation of analog circuit analysis”, 2001

7. Defended theses

“Development of circuits lab”, 2003

“Renewing of circuits lab”, 2000

8. Main areas of scientific work/Current research topics

Home and remote labs

9. Other research projects

Development and automating of chemical measurements at the Institute of Chemistry of Tallinn University of Technology

**DISSERTATIONS DEFENDED AT
TALLINN UNIVERSITY OF TECHNOLOGY ON
INFORMATICS AND SYSTEM ENGINEERING**

1. **Lea Elmik**. Informational modelling of a communication office. 1992.
2. **Kalle Tammemäe**. Control intensive digital system synthesis. 1997.
3. **Eerik Lossmann**. Complex signal classification algorithms, based on the third-order statistical models. 1999.
4. **Kaido Kikkas**. Using the Internet in rehabilitation of people with mobility impairments – case studies and views from Estonia. 1999.
5. **Nazmun Nahar**. Global electronic commerce process: business-to-business. 1999.
6. **Jevgeni Riipulk**. Microwave radiometry for medical applications. 2000.
7. **Alar Kuusik**. Compact smart home systems: design and verification of cost effective hardware solutions. 2001.
8. **Jaan Raik**. Hierarchical test generation for digital circuits represented by decision diagrams. 2001.
9. **Andri Riid**. Transparent fuzzy systems: model and control. 2002.
10. **Marina Brik**. Investigation and development of test generation methods for control part of digital systems. 2002.
11. **Raul Land**. Synchronous approximation and processing of sampled data signals. 2002.
12. **Ants Ronk**. An extended block-adaptive Fourier analyser for analysis and reproduction of periodic components of band-limited discrete-time signals. 2002.
13. **Toivo Paavle**. System level modeling of the phase locked loops: behavioral analysis and parameterization. 2003.
14. **Irina Astrova**. On integration of object-oriented applications with relational databases. 2003.
15. **Kuldar Taveter**. A multi-perspective methodology for agent-oriented business modelling and simulation. 2004.
16. **Taivo Kangilaski**. Eesti Energia käiduhaldussüsteem. 2004.
17. **Artur Jutman**. Selected issues of modeling, verification and testing of digital systems. 2004.

18. **Ander Tenno.** Simulation and estimation of electro-chemical processes in maintenance-free batteries with fixed electrolyte. 2004.
19. **Oleg Korolkov.** Formation of diffusion welded Al contacts to semiconductor silicon. 2004.
20. **Risto Vaarandi.** Tools and techniques for event log analysis. 2005.
21. **Marko Koort.** Transmitter power control in wireless communication systems. 2005.
22. **Raul Savimaa.** Modelling emergent behaviour of organizations. Time-aware, UML and agent based approach. 2005.
23. **Raido Kurel.** Investigation of electrical characteristics of SiC based complementary JBS structures. 2005.
24. **Rainer Taniloo.** Ökonoomsete negatiivse diferentsiaaltakistusega astmete ja elementide disainimine ja optimeerimine. 2005.
25. **Pauli Lallo.** Adaptive secure data transmission method for OSI level I. 2005.
26. **Deniss Kumlander.** Some practical algorithms to solve the maximum clique problem. 2005.
27. **Tarmo Veskioja.** Stable marriage problem and college admission. 2005.
28. **Elena Fomina.** Low power finite state machine synthesis. 2005.
29. **Eero Ivask.** Digital test in WEB-based environment 2006.
30. **Виктор Войтович.** Разработка технологий выращивания из жидкой фазы эпитаксиальных структур арсенида галлия с высоковольтным р-п переходом и изготовления диодов на их основе. 2006.
31. **Tanel Alumäe.** Methods for Estonian large vocabulary speech recognition. 2006.
32. **Erki Eessaar.** Relational and object-relational database management systems as platforms for managing softwareengineering artefacts. 2006.
33. **Rauno Gordon.** Modelling of cardiac dynamics and intracardiac bio-impedance. 2007.
34. **Madis Listak.** A task-oriented design of a biologically inspired underwater robot. 2007.
35. **Elmet Orasson.** Hybrid built-in self-test. Methods and tools for analysis and optimization of BIST. 2007.
36. **Eduard Petlenkov.** Neural networks based identification and control of nonlinear systems: ANARX model based approach. 2007.

37. **Toomas Kirt**. Concept formation in exploratory data analysis: case studies of linguistic and banking data. 2007.
38. **Juhan-Peep Ernits**. Two state space reduction techniques for explicit state model checking. 2007.
39. **Innar Liiv**. Pattern discovery using seriation and matrix reordering: A unified view, extensions and an application to inventory management. 2008.
40. **Andrei Pokatilov**. Development of national standard for voltage unit based on solid-state references. 2008.
41. **Karin Lindroos**. Mapping social structures by formal non-linear information processing methods: case studies of Estonian islands environments. 2008.
42. **Maksim Jenihhin**. Simulation-based hardware verification with high-level decision diagrams. 2008.
43. **Ando Saabas**. Logics for low-level code and proof-preserving program transformations. 2008.
44. **Ilja Tšahhrov**. Security protocols analysis in the computational model – dependency flow graphs-based approach. 2008.
45. **Toomas Ruuben**. Wideband digital beamforming in sonar systems. 2009.
46. **Sergei Devadze**. Fault Simulation of Digital Systems. 2009.
47. **Andrei Krivošei**. Model based method for adaptive decomposition of the thoracic bio-impedance variations into cardiac and respiratory components.
48. **Vineeth Govind**. DfT-based external test and diagnosis of mesh-like networks on chips. 2009.
49. **Andres Kull**. Model-based testing of reactive systems. 2009.
50. **Ants Torim**. Formal concepts in the theory of monotone systems. 2009.
51. **Erika Matsak**. Discovering logical constructs from Estonian children language. 2009.
52. **Paul Annus**. Multichannel bioimpedance spectroscopy: instrumentation methods and design principles. 2009.
53. **Maris Tõnso**. Computer algebra tools for modelling, analysis and synthesis for nonlinear control systems. 2010.
54. **Aivo Jürgenson**. Efficient semantics of parallel and serial models of attack trees. 2010.
55. **Erkki Joason**. The tactile feedback device for multi-touch user interfaces. 2010.
56. **Jürgo-Sören Preden**. Enhancing situation – awareness cognition and

reasoning of ad-hoc network agents. 2010.

57. **Pavel Grigorenko.** Higher-Order Attribute Semantics of Flat Languages. 2010.

58. **Anna Rannaste.** Hierarcical Test Pattern Generation and Untestability Identification Techniques for Synchronous Sequential Circuits. 2010.

59. **Sergei Strik.** Battery Charging and Full-Featured Battery Charger Integrated Circuit for Portable Applications. 2011.

60. **Rain Ottis.** A Systematic Approach to Offensive Volunteer Cyber Militia. 2011.

61. **Natalja Sleptšuk.** Investigation of the Intermediate Layer in the Metal-Silicon Carbide Contact Obtained by Diffusion Welding. 2011.