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Author(s): Vesapuisto, Maarit; Ellonen, Otto; Vekara, Timo

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Improving the Learning Process of Circuit Analysis at University of Vaasa

Maarit Vesapuisto
School of Technology and Innovations
University of Vaasa
Vaasa, Finland
Maarit.Vesapuisto@uwasa.fi

Otto Ellonen
School of Technology and Innovations
University of Vaasa)
Vaasa, Finland
Otto.Ellonen@uwasa.fi

Timo Vekara
School of Technology and Innovations
University of Vaasa
Vaasa, Finland
Timo.Vekara@uwasa.fi

***Abstract*—From the point of view of a technology student at the University of Vaasa, the first compulsory course in Circuit Analysis in Electrical Engineering seems to be one of the most challenging in the first year of study. This paper presents the current situation and focuses on searching for various possibilities that could solve the observed learning problems. One deficiency that we have observed is the student's undesired way of solving problems in Mathematics and Physics without drawing a draft picture, which leads to poor learning outcomes. Another problem that we have observed is the inadequacy of students' mathematical skills and routine in solving problems. A method used in calculation exercises, where the students present and explain the solutions they have made to others using a document camera in classroom or by using Zoom and sharing their screen, has proven to be a success in terms of both time and learning. To further facilitate the learning, digital learning materials and interactive learning processes have been developed. From their own computers students can independently solve problems online in STACK (System for Teaching and Assessment using a Computer Algebra Kernel) which is located on a server. The use of the learning platform makes it possible for every student to have their personalized problems and to instantly get direct feedback on whether the problem is solved correctly or not. In this way, we can proceed in small learning steps to improve the students' possibilities of achieving the needed knowledge and skills. The use of repetition and testing brings out routine that provides a basis for high-quality and understanding learning.**

Keywords—interactive learning, circuit analysis, visualisation, STACK, remote teaching, JSXGraph

I. INTRODUCTION

In engineering subjects in particular, it has been observed that many starting students have an insufficient basic knowledge of mathematics and physics, in order to enable studies to proceed as scheduled. In many European universities, computer-assisted approaches have been developed, to support students in improving their basic understanding of relevant subjects [1]–[5].

Generally, an important goal of engineering education is the acquisition of problem-solving skills. New knowledge and conceptual understanding are both built on existing knowledge. Using visualisation aids in elucidating abstractions to help students form mental visual images and make visual interpretations of what concepts mean [6].

The University of Vaasa (UV) has provided education in the field of Electrical Engineering since 1997. In 2004, the UV was given the right to award degrees in the field of technology. Since then, the students have been able to undertake a full degree of Bachelor, Master and Doctor of Science in Technology. Currently, the annual intake of students for the studies of B.Sc. (Tech.) is 90. Students can choose one of the three different Degree Programs: 1) the Electrical and Energy Technology (EE), 2) the Automation and Computer Science and 3) the Industrial Management and Engineering. Over the past decade the UV School of Technology and Innovations (until year 2017 Faculty of Technology) has focused on centering education on early-stage studies and also in streamlining the development of teaching approaches that recognize the students' different basic skills and learning styles [7]–[9], as elsewhere in the world [10].

This paper presents how the course Circuit Analysis A (CA_A) has been built to improve the learning process for the students. Interactive learning and flexibility have been increased through the introduction of the STACK system and in every learning activity the focus is on visualisation. A detailed description of using STACK at UV is in [11].

II. COURSE CIRCUIT ANALYSIS A AT UV

Since the launch in 1999 the program of Electrical Engineering has been successful in Vaasa region from students', employers' and university's point of view. The program is based on study on a need of engineers in Vaasa and planned by Prof. Vekara. The EE program has focused on studying the fields of electrical engineering, e.g. Power Systems, Electric Machines, and Power Electronics, whose expertise is in great demand in the industry in Vaasa and its nearby area. The comprehension of applications in electrical engineering requires a good knowledge of the basics. Students have to understand the basic components used in a circuit, various laws and basic solving methods. In addition, the students have to be able to apply these successfully in different situations.

After completing the course CA_A, the student understands the basic laws of circuitry and is able to solve simple problems in continuous direct current (DC) and alternating current (AC) circuits, as well as solve the functioning and compensation needs of smaller DC and AC circuits containing controlled sources, transformers, and passive filters. Another learning outcome is that the student is able to use calculator and circuit simulation software to solve simple circuits and is able to make a simple report of their simulations. In addition, throughout the course, emphasis is placed on the prevailing engineering ethics, standards and regulations in the field of electrical power engineering, as well as the attitude related to their observance [12].

A. Students and Teachers

The first-year course CA_A is obligatory for students who are making a degree of Bachelor of Science in the Electrical Engineering and Energy Technology. In the last academic year, 58 students signed up to the course, and this year 70 students are attending the course.

The following teaching and guidance resources are available for the course:

- lecturer who produces and manages the calculation exercises, simulation exercises, midterm exams and exams in addition to lectures;
- student assistant who helps the students to solve the exercise problems in groups;
- a project-based STACK-specialist who produces and manages STACK problems for the students;
- a teaching assistant, who already in advance informs, encourages and guides the students to form small study groups.

B. Prerequisite Courses

It is assumed that the students have earlier achieved upper secondary school advanced mathematics and physics with a good grade [13]. In addition, it is also assumed that the students have beforehand carried out successfully the following bachelor-level mathematics and physics courses during the first semester: Basics of Technical Mathematics, Calculus, Linear Algebra I, Mechanics, Introduction to Electrical Energy Systems, and Electrical Measurements of Direct Current. Laboratory works related to DC and AC circuits are given before the course CA_A [14].

C. Lectures and content of Circuit Analysis A

The course CA_A consists of lectures (13 times two hours), calculation exercises (13 times two hours), and instruction of simulation assignment (2 times four hours). The students are also introduced to solve individually STACK problems about the subjects of the course. Student workload is 135 h, out of which scheduled study 60 h. The whole course lasts for 15 weeks.

The topics of lectures are as follows:

- The basic circuit elements: resistance, capacitance, inductance, independent sources, controlled sources and transformer.
- Analysis methods for DC and AC circuits: circuit transformations, mesh, nodal, superposition, Thevenin's, and Norton's methods.
- Basic filters and resonance circuits.
- Power matching and reactive power compensation.
- Analysis of symmetrical three-phase circuits.

III. IMPLEMENTATION OF THE COURSE AND ITS PEDAGOGY

The teaching methods and approaches used should accommodate a diversity of learning styles and help students use their strengths and improve on their weaknesses [12].

This section explains the structure of the course in detail. In Fig. 1 the realization of the course CA_A is presented in its current form. In Fig. 1 prerequisite courses or preliminary measures are not shown.

Fig. 1 shows how lectures, STACK exercises and calculation exercises follow each other on the weekly bases. The first six weeks deal with continuity mode DC and basic circuit solution methods, and over the next seven weeks, the continuity mode AC and related applications will be explored. The students can test their knowledge of DC electricity and methods in a voluntary midterm exam 1 (ME1) in week 8 and proficiency in AC and its applications in a voluntary midterm exam 2 (ME2) at the end of the course, or take the entire final exam (FE) at the end of the course. Circuit simulations begin in week 10.

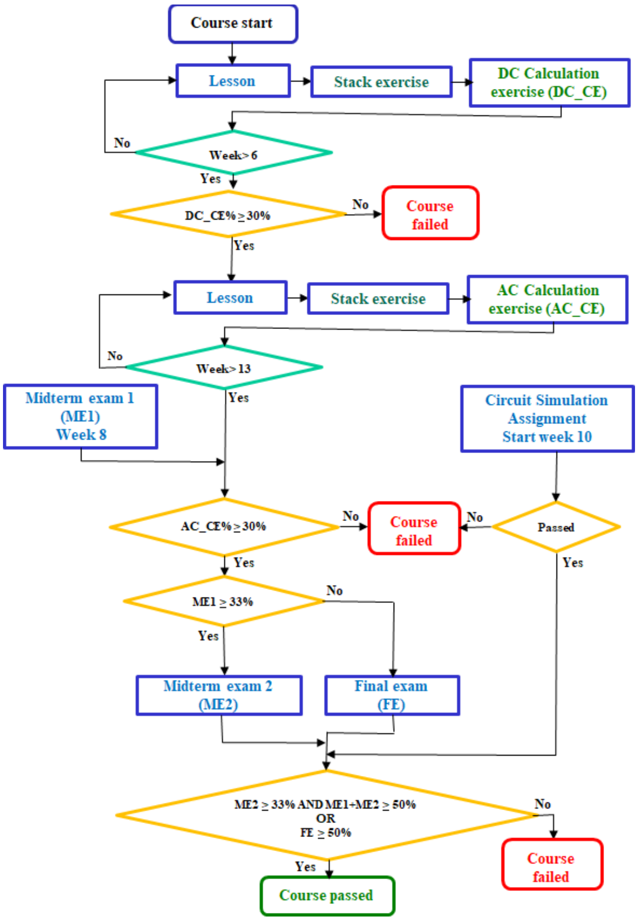

Fig. 1. Progress of the course CA_A.

A. Preliminary inquiry and support

Before the beginning of the course a preliminary inquiry is performed for the students (earlier this was done with pen and paper, now via internet).

The preliminary inquiry contains solvable problems about high school level mathematics and physics. In Table I a physics question of the year 2018 is introduced. As the mathematical problems, the students are asked to solve simple differential and integral functions e.g. differentiate the function $3\cos(10–4x)$ or integrate the function $\sin(5x)$ for x.

The purpose of the preliminary inquiry is to detect the different fields in mathematics and physics that need a recap before the beginning of the course. In addition, the aim is also to raise the students' awareness of their own current skills.

TABLE I. PREREQUISITION QUESTION CONCERNING QUANTITIES APPEARING IN ELECTRICAL ENGINEERING. "FILL IN THE BLANKS".

Quantity	Symbol	Unit
Charge		
Current		
Voltage		
Reactive power		
Resistance		
Capacitance		

It has been observed yearly that a fair amount of the students has some sort of lack of knowledge of basic mathematics and physics. To help the students to acquire the needed skills before the course, basic learning material about mathematics and physics have been collected to the course Moodle page in the form of videos and literature. The students are encouraged to use those materials by themselves.

B. Lectures

Before each lecture the students are asked to familiarize themselves with the upcoming subject beforehand with the help of the course book [15]. The purpose of using the book and lecture material is to support novice learners in their initial learning experiences in introductory circuit analysis which is justified for the following reasons: 1) the book is in Finnish, 2) the book obeys the IEC standard consistently when dealing with circuit diagrams [16], symbols and quantities [17]–[18] and 3) the circuit diagrams follow a logical color coding of circuit quantities [19], and still the sequence of topics is the same as found in other popular texts [20]–[21].

The lectures are preferably held traditionally in a class room to allow and encourage the students to ask more questions about different ambiguities during the lectures. However, during the past two years the lectures were shifted to online-teaching due to the pandemic. The lectures were held through Zoom (a video communication tool). At the same time the lectures were recorded in small parts and shared for the students in the course using Moodle so the students can recap later on.

Technically, the execution of the lectures online worked really well. However, in practice many students struggled to learn and absorb the course subjects with pure distance learning.

The advantages of traditional lectures are that the theoretical aspects can be explained for the students more naturally through physical and real-life references. For example, the reference arrows for voltages and currents can become more familiar if they are thought in the same way as connecting a multimeter to a circuit. In addition, the different potential nodes can be observed more easily if the students can see them in a physical circuit e.g. terminals connecting the components.

C. STACK exercises

The STACK system was created by Chris Sangwin during the early 21st century and is still being developed today [22]. It is a Moodle plug-in question type where the students type their own answers and the system responds by giving automatic feedback accordingly [23]. Instead of choosing from a set of given choices e.g. in a multiple choice question, in STACK system the students have to write their own answer. This tries to eliminate the guessing aspect of a multiple-choice question. The system allows the teachers to create problems for the students in different fields, e.g. in circuit analysis, mathematics and physics.

The advantage of the system is its ability to automatically give personalized feedback for the students based on their answer for a question. The system compares the students answer to pre-defined variables through algebraic tests and based on the results a proper feedback is given for them immediately after they have answered the question. This can be especially helpful if the students have made any mistakes. With the help of the personalized feedback students might realize relatively easy what went wrong when they tried to resolve the question.

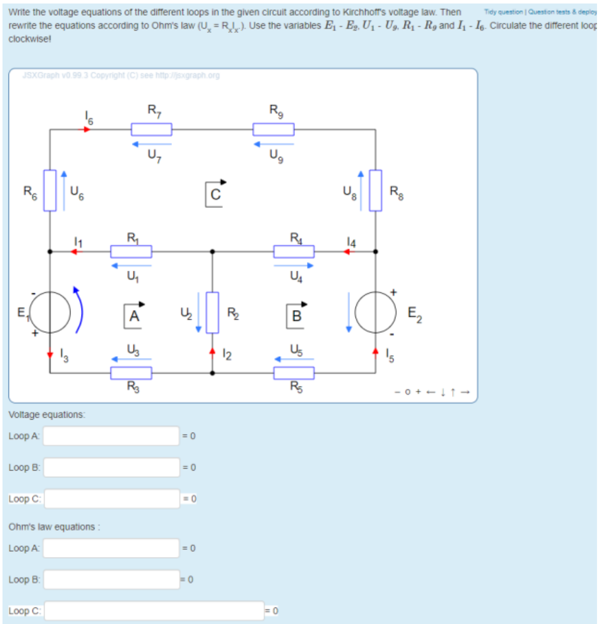

Fig. 2. An example of a STACK problem using JSXGraph to produce visual help for the students. Each of the voltage and current arrows shown are randomized every time the students try to solve the problem [24].

STACK problems may include visual help for the students in the form of traditional pictures (PNG, JPG, etc.), videos or images using third party JavaScript-libraries. One of such is JSXGraph. This library can be applied to draw geometrical shapes and to produce images for a given problem. An advantage of using JSXGraph is that the shapes can be controlled with the same variables used in the question text of a STACK problem. This feature becomes very useful if any randomization is involved in the problem. As an example, in Fig. 2, a STACK problem with a circuit diagram and three loops is produced by using JSXGraph. The voltage and current arrows are also created with the help of the library. In this particular problem randomization is implemented in a way that the direction of each of the arrows is randomized every time the students try to solve it. In a problem with this many changing variables it is almost impossible for the students to input the right answers simply by guessing. This forces the students, in addition with a proper feedback, to solve the problem correctly.

D. Calculation Exercises

At the beginning of each lecture the students have access already to the exercises related to the lecture. These are available on paper and digital and the students have one week to solve and finally show their solution in calculation exercise lecture.

The students are encouraged to do the exercises in small groups rather than alone to make the learning experience more efficient. In addition, during the past years a workshop to support the exercises has been available. In these workshops a senior student guides the participants to solve the problems.

The students use either preferably pen and paper or modern tablets to solve the exercises. This teaches them to draw the circuit components and quantities according to the IEC standard and makes it easier to remember them deeply rather than through a computer program e.g. typing just the numerical answers or answering multiple choice questions.

The solutions for the exercises are provided in exercise lectures. The size of the exercise group is aimed to be max. 20 students with multiple groups available. Nowadays, the students upload their solutions as pictures in Moodle before the exercise lectures which can be easily accessed in the class room or remotely in Zoom.

In the exercise lectures the traditional blackboard has been replaced by modern technology. The students can share their solutions via a document camera or if they are attending remotely this can be done through Zoom. The camera feed can be projected on a white screen so that the whole class can see it. This is more efficient than rewriting their solution for each problem and thus more time can be used on analyzing the solution. In Fig. 3 a student is presenting his solution for an exercise problem physically via document camera. In Fig. 4 a student is presenting her answer to the physical classroom as well as for the remotely attending students through Zoom during a hybrid exercise lecture.

During the exercise lecture each problem is analyzed individually before moving to the next one. A student is chosen randomly out of the students who have tried to solve the given problem to present the solution for it. The chosen student then proceeds to explain the problem and its solution

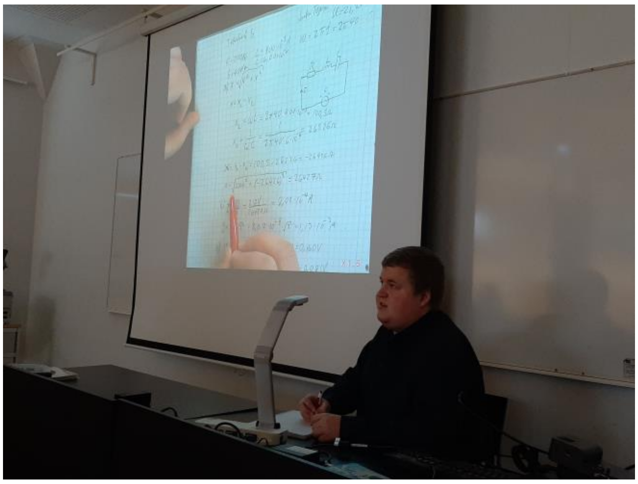

Fig. 3. A student presenting his solution to the class via document camera in an exercise lecture (before the pandemic).

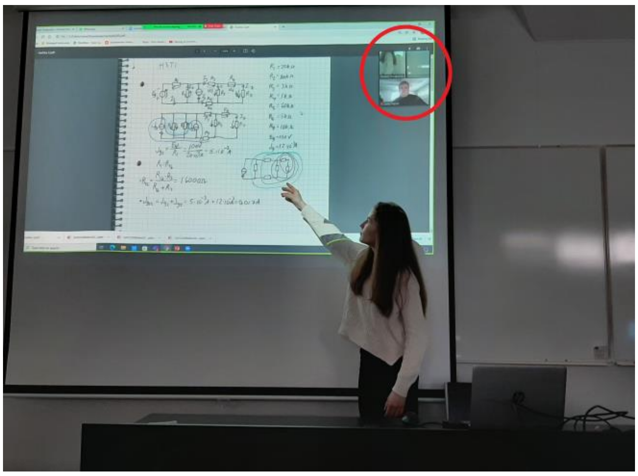

Fig. 4. A student presenting her answers to both students attending the exercise lecture physically and remotely (during the pandemic).

verbally using the correct terminology e.g. saying out loud 'resistance' instead of saying just '*R*'. This enforces the student's ability to absorb the correct terminology better. Other attending students are encouraged to comment on the presented solution and possibly present their own way of solving the problem. The verbal and visual learning styles are taken into account during the procedure.

E. Simulation exercises

When the students have obtained the necessary basic knowledge on DC and AC circuits they are introduced to perform simulation assignment beginning in week 9. The simulation runs parallel with the mentioned lectures and exercises. The simulation exercises are done in groups of 2–3 students and each group will have their own personalized circuits with different initial conditions. Before running the simulations, each group has, as a preliminary problem, to solve their circuits quantities by hand. This is done to give the students some sort of reference when they start to simulate. Three simple circuits are solved in the simulation exercises: 1) continuous DC circuit, 2) continuous sinusoidal AC circuit and 3) a simple filter circuit. Simulations are done by using Aplac's student version [25].

In the first simulation exercise lecture the students receive instructions on how to use the Aplac software. It is a step-by-step guide with pictures that includes everything the students need to know about using the software. Then a demonstration of the working and functioning principles of the simulation program also takes place.

In Fig. 5 the first simulation exercise is introduced. It is a simple DC circuit with a DC source and three resistors. The students first simulate with the given initial values and then they have to chance something e.g. the values of the resistors and simulate again. After they have done the two simulations the students have to analyze the results, i.e. how the change affected the circuit's voltages and currents.

In the other simulation exercise the students are introduced to an AC circuit shown in Fig. 6. Again, the students first simulate the circuit using initial values for the components and then change some values and simulate again. Now the students have to analyze how the changes affect the voltages, currents and phase angles.

In the final simulation exercise the students have to simulate a filter circuit pictured in Fig. 7. During the

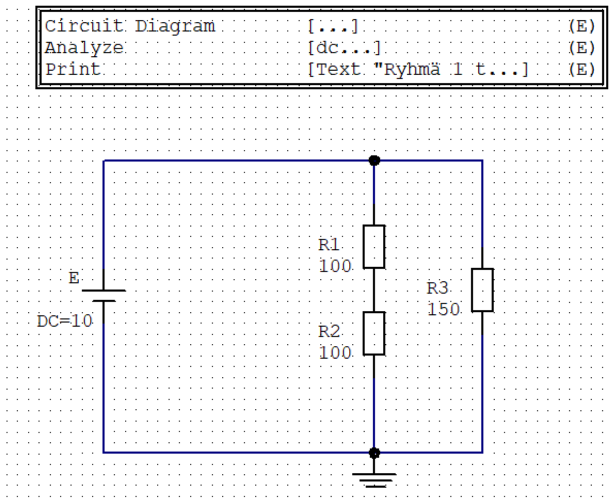

Fig. 5. DC circuit for the first simulation exercise.

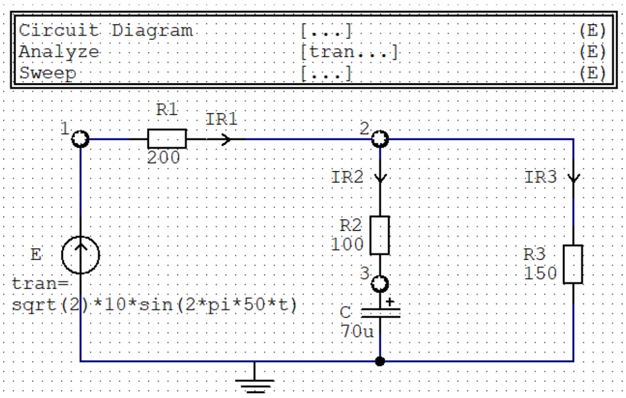

Fig. 6. AC circuit for the second simulation exercise.

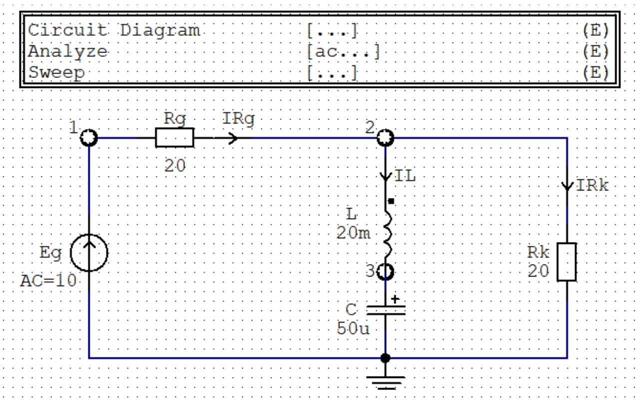

Fig. 7. A filter circuit for the final simulation exercise.

preliminary problems the students have to identify the filter type. After the simulation the students confirm their answer by looking at the circuit's frequency response from the simulation.

Finally, the group has to collectively write a report about the simulation results including analysis according to the writing guidelines of University of Vaasa.

There are couple of reasons, why this approach has been chosen. The purpose of the simulation exercise and report is to produce empiric experiences about the working life applications for the students which will motivate them. In addition, the group work teaches the students teamwork, programming skills, verbal (oral and written) skills and logical thinking. Groups, in which the students work as a team, have achieved excellent competence which has led for them to pass the course successfully. Unfortunately, in some groups the work is divided into sections e.g. each member does just their 'own' simulation and writes about it and in the end the parts are combined. Generally, in these cases, the final results have not been satisfactory.

F. *Exams*

To pass the course the students have to successfully carry out an examination. This can be achieved by either doing a final exam or by successfully passing the two midterm exams.

First midterm exam tests the students' abilities to understand the basic rules of DC circuits (Kirchhoff's and Ohm's laws) and solving methods e.g. nodal and mesh analysis. The second midterm deals with the basics of AC circuits e.g. new quantities, filters and reactive power compensation. To attend the two midterm exams the students, have to acceptably calculate at least 30% of the respective midterm exercises (DC_CE% and AC_CE% in Fig. 1). Similarly, to attend the final exam the students, have to calculate 30% of both individual midterm exercises. It consists of problems from both midterms. In each case the student has to get 50% of the total points of the exam. This means that the students who are passing the course with midterm exams have to, in addition, get 50% of the total points of the two midterm exams to pass the course.

There are couple of reasons, why this approach is chosen. Each student has to learn how to apply the basic quantities, laws and solving methods sufficiently enough to pass the following electrical engineering courses. These advanced courses deal with applications and need the knowledge of the basics and it is vital that everyone has the skills.

IV. Conclusion

This paper presents the current situation of education of the Circuit Analysis A course at UV and focuses on searching for various possibilities that could solve the observed learning problems. Let us now first look at general items.

The consistent and logical use of visual presentation of electrical circuit quantities makes it easier for the students to grasp on the substance during the first lectures: same things are expressed in the same way.

To absorb the necessary skills and knowledge during the course CA_A is vital for the students when they are performing next courses in electrical engineering.

Quality of education is assured by testing students' knowledge and skills in small steps by using reasonable amount of STACK exercises, then calculation exercises, simulation exercises and finally entire course content in final exam. At UV STACK exercises are located in between lessons and calculation exercises as shown in Fig. 1.

The students are encouraged and forced to use the correct terminology in lectures, exercises and simulations. This has improved the learning process for the students who have accepted these rules. On the other hand, some students feel that the course is very challenging because they are unable to carry it out with the old familiar way of just memorization.

Additionally, we have made the following detailed attentions and measures, and planned for future actions.

A. *Problems detected in learning*

We have found, that not only the students' starting level varies, but also they might not learn, because they have not enough motivation, do not want to make exercises or simulations, are missing a calculation routine, do not draw when solving problems, try to copy or rely solely on memory etc.

B. *Suggested solutions*

We have tried to solve the problems using following measures:

- Preliminary tests are used and revision material is available at the beginning of the course.
- The student sees correct standard drawings in the question sections of the assignments, also in STACK's JSXGraph assignments.
- The student is encouraged and forced to draw, calculate and present solutions.

- We have assured a safe learning atmosphere, where mistakes are allowed and learned from, when the student orally or in writing presents solutions.
- The student gets enough calculation routine by using STACK and solving calculation exercises, which also assures an accurate way of working.

C. Experiences of using suggested solutions

The sStudents who have genuinely embarked on the learning process and completed all the STACK assignments know things thoroughly and receive an excellent grade.

Learning is a process consisting of small steps. We have successfully used STACK to lower learning steps. Additionally, JSXGraph is used to increase visualisation and personalization from which results are encouraging. In drawings we continue to use standard-based symbols and colors in circuit diagrams, which help the first-year students in understanding learning, which emphasizes the importance of in-depth understanding rather than memorizing information.

Flexibility in timing of studies is here achieved by using weekly STACK exercises, simulations using Aplac software during several weeks and midterm exams.

Inevitable drawbacks for students due to digitalization can partly be tackled by using: individual calculation by hands, student presentations to the other students, group reports, discussions and other team working processes with other students, and interactive and personalized STACK problems. STACK problems can be done regardless of time and space as long as the students can access Moodle.

Presented teaching and learning practices can also be used in remote learning, but generally, student's learning alone should by any means to be avoided to achieve effective learning process.

During the years we have started to use new teaching methods: from the traditional blackboard we have first moved to use document camera and nowadays computers and drawing screens. The advantage is that the lecture notes and drawings can be saved and shared for students to use later.

D. Future actions

In the future the aim is to produce digital exams with the STACK system which could be done in a supervised environment. These exams could be evaluated automatically without the teacher's interference. The course is being developed towards a more flipped learning style. This puts more emphasis for the students to prepare for the lectures. Also, in mathematics and physics the presented actions could be applied more widely. Hopefully, learning process will take place in smaller groups which will improve the learning experience.

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