First Experiences in Using STACK in Education of Circuit Analysis at University of Vaasa

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***Abstract*— The first compulsory courses in circuit analysis for the technology students at University of Vaasa create an important basis for the studies on Electrical Engineering. Here, the particular challenge for teaching has proven to be the creation of a new way of thinking for students, who have used memorisation as their primary learning method. The first-year students have a heterogeneous starting level in knowledge and skills. This paper focuses on the positive experiences received at University of Vaasa from utilizing visualisation, interactivity, repetition and testing in learning in an environment called STACK (System for Teaching and Assessment using a Computer algebra Kernel) which operates in the web browser. We have developed simple and representative problems of circuit analysis, which through repetition introduces students into a new way of thinking and subjects them into deep learning. Additionally, the problems can be solved regardless of time and place, even in one's own personal pace. At the end of the course, feedback on using STACK has been collected from the students. It has been almost entirely positive, and more problems have been desired. It is found that students that did more exercises also passed the course with better grades.**

***Keywords*— education, interactivity, circuit analysis, STACK, visualization, JSXGraph**

I. Introduction

In the core of electrical engineering lies circuit analysis, a fundamental special case of electromagnetism. Circuit analysis combines complex physics and mathematics in a simplified way so that e.g. designing complex circuitry is a quicker way than using complicated formulas from electromagnetic field theory.

In universities around the world circuit analysis is being taught during the first and second year of electrical engineering studies. The beginning of the studies often focuses on the fundamental theories in mathematics and physics. After the students have grasped the basic theories, more advanced theories and applications can be absorbed. Based on our years of teaching experiences and learning standpoint, we have observed that circuit analysis only seems simple.

Internet or web-based learning has been used in teaching circuit analysis already in the 1990s [1],[2]. Since then the available software and learning environments have increased in number and become more sophisticated. In today's world students have access to internet from almost anywhere due laptops or smart phones. This opens new possibilities for developing new learning methods and tools for the engineering students [3]. It has also been observed that some electrical engineering students in universities have insufficient skills in mathematics and physics. This delays the scheduled studies. In order to solve this problem computer-assisted approaches have been developed in European universities [4]–[8].

One of the computer-assisted approaches is STACK. It is a Moodle (Modular Object-Oriented Dynamic Learning Environment) plug-in question type that focuses specifically on giving feedback that depends on the students' answer. Moodle is a learning platform that operates in the web browser [9]. The system is widely used in universities in Finland and also in other countries [10]–[12]. At the University of Vaasa STACK has been integrated in courses since the early 2010s. At first it was used in mathematics but since 2019 it has also been used in circuit analysis and later in physics.

This paper presents the positive experiences of using STACK in education of circuit analysis at University of Vaasa. Interactive and visualized circuit analysis problems have been generated for the students thus providing automated feedback dependent on the students' answer. These problems can be carried out whenever and wherever as long as the students have access to Moodle. Due to the automated feedback given by the system, these problems can be solved by the students themselves. The feedback gathered from the students has been very positive throughout the last years and the quality of the learning process has improved.

II. STACK, automated Feedback and Visualization of Circuits

The STACK was created by Chris Sangwin during the early 21st century and is still being developed today [13]. It is a Moodle plug-in question type where the system evaluates the students answer and gives feedback according to the given answer [14]. The big difference compared to other question types inside Moodle is that in a STACK-question the students have to give the short answer by themselves by writing it on an input field rather than for example choosing the right answer from a list of multiple choice questions. After the students have given their answers the system compares it, usually algebraically, to a pre-defined right answer. After the evaluation, an individual feedback is given automatically and immediately for the students based on their answer. This approach tries to eliminate the existing guessing aspect of the multiple choice questions and lets the students solve the question completely with just the assignment text.

It is also relatively easy for the teacher to produce slightly different questions through randomization instead of creating every possible question. This makes it harder for the students to use memorization because every question is a little bit different and forces them to learn how to solve the given problem properly.

A. System requirements

STACK-question type is a Moodle plug-in so it can be installed to a pre-existing Moodle-server. Since the questions are in Moodle they can be accessed with every device that has a web browser. This also means that the students are able to access the questions from their own devices as well.

B. Response Tree and Generated Feedback

The important pedagogical part about the STACK-questions for the students is the personalized feedback given to them. The automated feedback produced by STACK is generated by comparing the students' answers to different pre-defined answers and variables through different, usually algebraic, tests. They are created by the teacher. In STACK these tests occur in a so-called *node.* The node performs the test and has two outputs: one if the test equals true, i.e. when the student's answer matches a pre-defined one, and the other if the test equals false. A feedback message which will be shown for the students can be written on the output of the node. There is a possibility to connect nodes to each other which results in a tree-like structure, hence the name *Response Tree*. When a student gives an answer the Response Tree is traversed from top to bottom depending on the answer. A proper feedback is given to the student regarding the student's answer. A simple Response Tree structure is shown in Fig. 1.

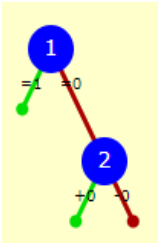


Fig. 1. A Response Tree consisting of two nodes connected to each other through node 1 *false*-output (red line).

With more nodes it is possible to conduct more tests and try to pinpoint a detailed mistake the students have done and thus improving answering quality. With appropppriate feedback the students can understand why the given answer was incorrect and learn from it. In Fig. 2. a very simple feedback is given to the students. The STACK-problem consists of multiple different parts. First we have the assignment (1). After it comes the input-box (2) where the students wrote their answer. This can be text, numbers, expressions etc. A validation field is located under the students' input (3). During the attempt this tells to the students how the system interprets the answer. Therefore, typing errors can be corrected before concluding the attempt. After the students have finished the attempt, the Response Tree is traversed by the system (4). This process is invisible for the students. Depending on the test results in the Response Tree according to the students' input, a suitable feedback is generated for them (5).

As we can see a student has used subtraction instead of addition and the system notices it. The feedback is tailored to best suit the situation and to inform the student about the mistake that was made. In this example the right answer is also given to the student. There is also a possibility to add score to an ouput of a node which gives the student more information about the severity of the mistake [15].

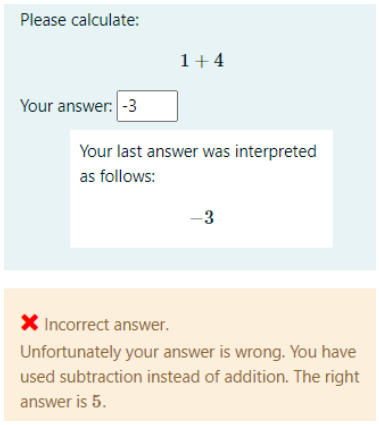


Fig. 2. A simple example of a STACK-question (from student perspective) and the feedback given to the student by the system according to the given answer.

C. Visualizing Questions by Using JSXGraph

Visualization is very important when we are dealing with problems that need a drawing in addition to an assignment e.g. circuit analysis where the schematic is a must, otherwise the problem is impossible to solve. There is a possibility to use static images and implement these to the question like in a traditional Moodle question. In some cases their use fulfills the needs and requirements. It is also possible to randomize these to acquire more variation in the questions [16].

There is also a possibility to use other methods for example JSXGraph. JSXGraph is a JavaScript-library implemented in the newest STACK-version which lets you mainly draw geometrical shapes by using a coordinate system. There is also a possibility to draw functions or graphs and even animations [17]. One of the reasons to use this library is that the coordinates of the shapes can be manipulated with variables used in the questions. This means that one can produce images which are related to the question even when using random variables without making hundreds of customized images.

In Fig. 3. a circuit diagram is produced with JSXGraph. The coordinates of the voltage arrows are manipulated with variables that change randomly each time students try to solve the question i.e. the direction of the arrows changes. This also changes the answer so the students can not e.g. copy and paste the solution from the last attempt directly.

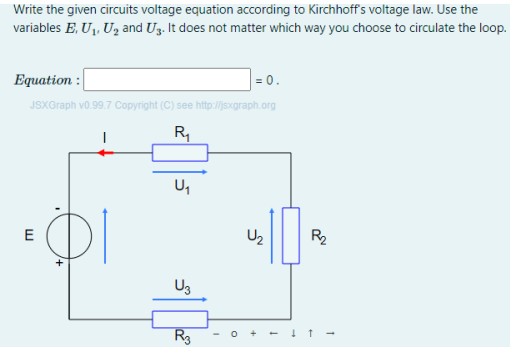


Fig. 3. A circuit diagram for the given problem drawn by using JSXGraph. Here arrow directions are manipulated with randomized variables.

The current and voltage arrows use different colors in the circuit schematics. This is another important visualization tool. The students' will understand the presented schematics better when colors are used to distinguish between electric quantities [18]. Additionally, technical students have a tendency for visual learning [19]. For example in Fig. 3. all voltage arrows are colored blue and the current arrow is colored red. At University of Vaasa this has been the standard in teaching circuit analysis. All the drawn components are created according to the IEC 60617 standard within the limits of the JSXGraph library. [20], [21].

III. APPLYING STACK-SYSTEM IN TEACHING CIRCUIT ANALYSIS AT UNIVERSITY OF VAASA

At University of Vaasa there are two circuit analysis courses: Circuit Analysis A (CA_A) which focuses on basic DC and AC circuits and is being taught during the 2nd semester and Circuit Analysis B (CA_B) which goes mathematically a bit deeper with transient analysis and transmission line theory and it is taught during the 3rd semester [22],[23].

In order to complete the engineering studies as scheduled it is critical for the students to pass the course CA_A successfully in order for them to even have a chance to pass the more advanced CA_B. If a student fails the first course and does not learn the basics of circuit analysis it is almost impossible for them to solve the more advanced tasks during the 2nd course. This means that failing the first course delays the studies at least by one semester.

At the beginning of the CA_A in 2022, a survey was conducted in order to find out more about the participants' background. The students were asked about their background in mathematics and physics prior to university studies and about successfully completed university courses. As a result it was found that the group is very heterogeneous in which some students have completed all the necessary courses in terms of mathematics and physics and some do not. The students with insufficient mathematical and physics background, have an increased chance of dropping out of the course, which as stated above will cause problems during the later studies.

Since 2019 in addition to other traditional study activities, such as lectures and exercises, the students have been given STACK-problems which have to be solved acceptably in order to carry out the course successfully.

A. STACK-Problems Used in Teaching Circuit Analysis

The STACK-problems used in CA_A differ a bit from the traditional exercises. The biggest difference is that in STACK we have not included almost any calculation at all. In most of the questions the students are asked to just produce an equation using the variables found in the circuit diagram. There are couple of reasons why this approach has been chosen. If students can produce the correct equation for the given problem, then replacing the variables with numbers and calculating the outcome becomes trivial. Another reason is that without calculation the answers can be typed without using pen and paper or calculators. This makes it much simpler and accessible for the students.

The problems are also constructed in a way that the students get a new version of the circuit every time they try to solve it. This can be done by randomizing the voltage arrows in circuits when dealing with Kirchhoff's voltage law or by simply randomizing the components in the circuit. This tries to eliminate the use of memorization and instead next time students try to solve the problem, it forces them to think about the theory more since copy and paste does not work. In very simple circuits the problems can be brute forced to some extend but later, when dealing with multiple loops the probability of getting the right answer by purely guessing becomes very small. This discourages the students in trying to guess the answer. The randomization also courages the students to try the problem again in order for them to train more on routine solving since the problem is different every time. Even the structure of the circuit can be changed randomly. This means that the connection between components can be altered to have a greater change via randomization.

The tasks vary from writing the needed Kirchhoffs voltage laws for different circuits to more advanced analysis e.g. producing matrices for using mesh or nodal analysis. In Fig. 4. a question dealing with nodal analysis is presented. The students have to fill the matrices correctly depending on the current version of the circuit. Again this involves no calculation at all.

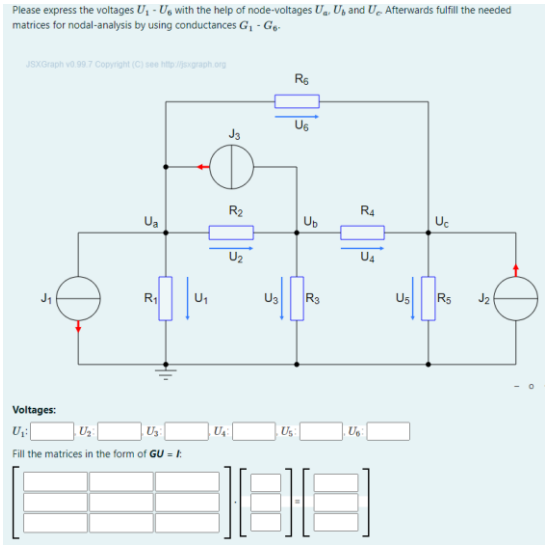


Fig. 4. A more complex problem where the students are asked to fulfill the matrices required for nodal analysis. There are no numbers or calculation involved. The structure and some parts of the circuit are also randomized.

In CA_A before STACK the students participated in a traditional lecture and afterwards to an exercises for which they had to solve problems regarding the lecture. The idea of using STACK is to make it easier for the students to grasp on the theory before involving any mathematics in solving circuits. For example in the problem in Fig. 4. a student does not have to solve the matrix, just fulfilling it is enough. It has been observed that fulfilling the matrices for nodal analysis has been problematic and by producing a wrong matrix a wrong answer is also produced when it is solved. This is why it is important to learn first how to fulfill the matrix correctly and after it comes the math. The mathematical part is done during the exercises which focus more on finding an asked value to complete the analysis.

The problem has been that the students do not usually know how to get started when trying to solve a circuit or how to apply Kirchhoff's laws properly. This makes it impossible to solve the given problems. STACK is closing the gap

between the lectures and exercises by first teaching the students the basic small learning steps in order for them to solve the more complex exercise problems.

B. *Presentation of the Problems for the Students*

The STACK problems have been presented to students by using Moodle-quizzes. The quizzes are constructed typically to include 1 to 3 problems of the same type. Due to randomization these problems are different during the quiz and when students attempt to solve the quiz again. The amount of problems in each quiz is dependent on how 'hard' or long the problems are. Usually, the amount of problems in a quiz is tied to the amount of loops in the circuit diagram:

- Circuits with 1 loop have 3 problems
- Circuits with 2 loops have 2 problems
- Circuits with 3 loops have 1 problem.

Since the circuits with more loops have more things to consider, i.e. more components, solving them is usually more time consuming than solving circuits with less loops. The 'additional' workload for the students must be kept in reasonable amounts so that it does not feel overwhelming to carry out these problems.

The amount of quizzes and problems inside them has varied during the years but the basic principle is the same. The quizzes are constructed to focus on the key parts of the course. The more simple problems are repeated multiple times in order for students to practice on routine solving and to produce many different situations for them where as the more complex ones are usually needed to be completed only once. The main idea is to advance step-by-step and theoretically if the students can solve the simplier ones they can proceed to solve the more complex circuits because the basic laws do not change, they are simply applied more times.

C. *Students' perspective regarding the STACK questions during the course*

Since the integration of STACK problems one of the requirements to pass CA_A successfully has been to complete the presented STACK problems. This means that the students have to complete the given quizzes with a perfect score before the deadline in order to pass. In other words the quizzes are a mandatory part of the course.

The students can carry out the quizzes as many times as they like even after completing them successfully. Because the idea is to first attend the lecture, then do the STACK quizzes related to the lecture and then proceed to solve the exercises there has been a deadline for the quizzes in order to make the students follow the right order of procedure more carefully.

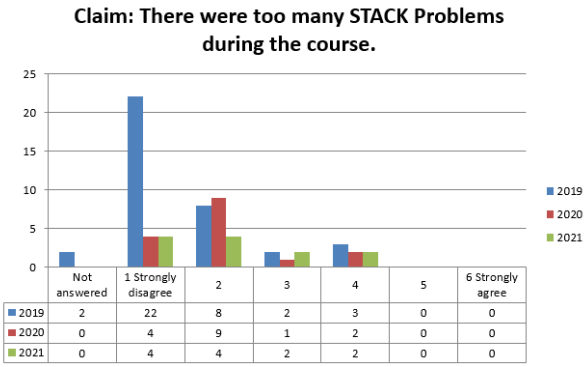
The perfect score demand is to ensure that students can try to solve the exercise problems without coming into a complete halt when they try to attempt to solve them. Knowing the absolute basics of Kirchhoff's laws or nodal-analysis for example, are a must before trying to solve circuits. The STACK problems are simple enough so doing them does not consume that much time even if students have to attempt the quiz multiple times. This has been confirmed by the students in multiple surveys which we discuss in the next chapter. On the otherhand every second used to carry out the quizzes is a second invested in doing the exercises since ultimately the students have to acquire these skills in one way or another.

IV. Student Feedback and Findings

The experience for using STACK problems as a part of the course has been very successfull from the teachers and students perspective. After each course completed from 2019 to 2021 a survey was conducted in order to get insight on how the students feel about this new type of material. The samplings for each year are N = 35 (2019), N = 16 (2020) and N = 12 (2021).

A. *Survey of student feedback from 2019 to 2021*

The feedback from the surveys has been very similiar in all the three courses. Fig. 5. shows a comparison between answers from different years to the same questions about the amount of STACK problems presented for the students. As we can see the students' answers vary from 1 to 4 on a scale of 1–6 where 1 means strongly disagree and 6 strongly agree. In each year most of the answers lie either in the category of 1

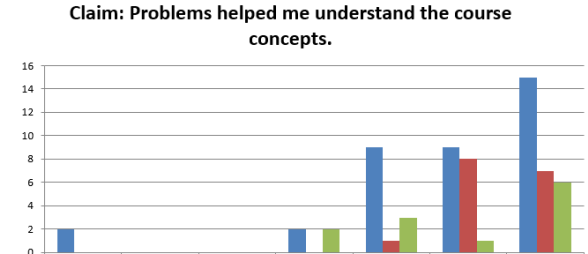


	Not answered	1 Strongly disagree	2	3	4	5	6 Strongly agree
2019	2	22	8	2	3	0	0
2020	0	4	9	1	2	0	0
2021	0	4	4	2	2	0	0

Fig. 5. A comparison between survey results from different years. The survey suggests that there were not too many problems presented for the students.

or 2, so it is safe to conclude that there were not too many problems presented for the students.

In other parts of the surveys the answers obey the same distribution for the same claims in different years i.e. there is little to no variation in distribution between the years. In Fig. 6. another positive result is shown regarding the students'



	Not answered	1 Strongly disagree	2	3	4	5	6 Strongly agree
2019	2	0	0	2	9	9	15
2020	0	0	0	0	1	8	7
2021	0	0	0	2	3	1	6

Fig. 6. A comparison between survey results from different years. The survey suggests that students felt that the STACK problems helped them learn the concepts of the course.

feelings about learning by using STACK problems. In all three cases the students felt that they learned the concepts with the help of STACK problems.

The surveys had also a open commentary section consisting of two parts where the students could write freely any detailed comments regarding the STACK problems. One part was for the positive things they found out about the problems and the other was for issues and development ideas for the future. In each year the positive comment section consisted mainly of the following or similar kind of comments:

- ”The problems were a good addition to existing material.”
- ”The instant feedback helped me to understand the solution to the problem easily.”
- ”The problems helped me to understand difficult concepts.”
- ”Could be used later to rehearse for the exam.”

The second part consisted of a few development ideas for the future for example the instructions on the form of the answer could be sometimes clearer. The biggest criticism that the students had was about the mandatory perfect scoring requirement. The students felt that making a simple sign mistake e.g. writing ”+” instead of ”-” in an equation ruined the whole attempt which would mean that the whole quiz had to be done again from scratch.

B. Further development and addressing the issues

The issue with the sign mistake has already been addressed and a solution to it has already been developed. In complex problems the students can check individual input fields, i.e. answers, if they are wrong or correct before ending the quiz. This makes it less tedious for the students as now they do not have to start from the beginning of the quiz. After checking the answer they can change it as many times as they like until it is correct. Of course now the feedback has also been changed so that it will not give the correct answer straight away when students try to check it. Instead a new feedback is given as a tip on what could be wrong and how it can be solved. If students have the correct answer the new feedback will inform about it. The whole correct answer appears when the whole quiz is returned.

Still a perfect score is needed in order for the students to pass the course. The reason is that in circuit analysis it is very important to get all the signs right, otherwise the answer will be false regardless of the rest of the calculation and it can lead to other problems during the calculation. It requires students to be extremely careful when writing up the equations and unfortunately they have to learn this somehow.

C. Concrete results in improving the learning process

Due to the compulsion of the STACK problems every course participant has to successfully pass them. This makes it hard to distinguish the impact the problems have had to grades compared to students that have not done them. Another unfortunate variable during the study was the sudden change of teaching to distance teaching and learning from 2020 onwards due to COVID-19 pandemic which undouptedly has had an effect on the learning process as well.

On the otherhand in a physics course at University of Vaasa called Electricity and Magnetism which was held during the fall semester of 2021, STACK problems were also included as a part of the learning process. The problems were this time not mandatory and it was completely optional to carry them out. Students could try to solve the problems as many times as they liked and a new version with e.g. different values was given for them everytime they tried to solve them. Out of the 33 students that solved at least one of the 13 STACK problems by getting some points, 14 passed the first exam. However, those students that did solve more of the STACK problems successfully also passed the exam with a higher probability. The average number of points gathered from the problems was 25.18 for students who passed the exam. For students that did not pass the exam, the same number was 12.98. This does not necessarily mean that the problems alone are the reason for the success e.g. the students who passed might have worked hard on the course anyway but still this gives a promising result with addition of the positive feedback that by doing the STACK problems the chances to pass the course increases.

The physics course is similar to the CA_A in the sense that they both share the same problems regarding the prior knowledge of the students. In that sense the results can be compared and one could argue that the STACK problems have a similar positive impact in circuit analysis.

V. CONCLUSIONS

The key features of STACK include individually tailored and automatic feedback that is given to the students which depends on their answer. This makes it possible for the students to solve these problems by themselves whenever where ever as long as they can access Moodle.

This paper presents our positive experiences about using STACK in circuit analysis education during the last three years. The problems regarding learning circuit analysis have been a challenge for a long time. With the help of STACK learning process the students have an easier way to combine the theory from the lectures with the practical work of the exercises by closing the gap between those two thus reducing the size of the learning steps. Therefore, the use of STACK is an addition to other teaching and learning activities. It is not a replacement.

The problems were presented for the students as a mandatory addition to the traditional course material. A weekly deadline for the problems was placed in order for the students to carry them out before the weekly exercises took place.

In three years feedback was gathered from the students after each course. The feedback was overwhelmingly positive and the students felt that doing the STACK problems in addition to other course material had a positive effect on their learning outcomes. Difficult concepts were more easily realised through the problems which helped the students to work on the more complex exercises. Couple of issues were also noted by the students which we have timely tried to address and fix.

Concrete results in improving the learning process in terms of better grades is hard to analyse since all the problems are mandatory. Also the COVID-19 situation has made it almost impossible to compare 2020 and 2021 courses to previous ones since the whole learning process moved to distance learning which had its own impact on the learning process. In physics course however it can be seen that the students that carried out more optional STACK problems performed better during the exam than the students that did not.

With the feedback from the students it is possible to develop our circuit analysis STACK-problems even further to better respond the needs. New ways to approach complex problems can be adopted e.g. the students can check their answers individually before ending the quiz to reduce the tediousness of starting over from the beginning . Other courses could also benefit from these problems due to the positive results gained. The STACK-system itself is developing continuosly because of its open-source nature and an active community. It will be interesting to see what the future development for the system will look like.

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