Circuit Theory E-Assessment Realized in an Open-Source Learning Environment

https://doi.org/10.3991/ijep.v9i1.9072

Marko Neitola
University of Oulu, Oulu, Finland
marko.neitola@oulu.fi

Abstract—This study discusses university-level e-education on circuit theory. Automatic assessment activities were realized in the learning environment Moodle with symbolic math enhancement plugin STACK. With a comprehensive set of self-study e-assignments, the desired outcome was to help the students to improve their conceptual understanding. Here, the instructional approach is to assign take-home e-activities during the course. The rationale for such approach is to guide the student to prepare themselves for the final exam. This study discusses the learning results in comparison with the traditional paper-assessments conducted in the previous year. E-activities can improve learning, but a lot of attention must be paid to two issues: realizing the activities and accompanying students' varying learning skills. Moreover, the structure of a circuit theory e-quiz differs from a typical mathematics quiz, which is also discussed here.

Keywords—Electrical Engineering Education, Circuit Theory, Open-Source, Educational Technology, E-Assessment, Moodle, STACK, Maxima

1 Introduction

Moodle [1] is a well-established and advanced learning environment for any scientific discipline: with the selection of more than 1,000 plugins, different pedagogic experiments, such as student assessment, are easily implemented. The STACK plugin for Moodle [2], [3] is remarkable as it enables mathematical input to be evaluated by a symbolic analysis software: STACK uses the kernel of Maxima [4], an open source symbolic analysis software. STACK was created by Chris Sangwin in 2004 [2] and judging by the related publications, e.g. [5]-[8], it has since then been used mainly as an e-learning or e-assessment tool in mathematics.

The intention of this work was to realize STACK-based take-home e-exams in the field of circuit theory. The goals were to improve the conceptual understanding and hence the learning results. The desired effect of the take-home e-activities was to alleviate the learning difficulties with the help of auto-assessment and well-designed automated feedback.

Section 2 introduces two circuit theory courses in which the Author continues to experiment with e-learning solutions. Here, typical learning difficulties in circuit theory are discussed.

Section 3 discusses realizing a circuit theory quiz in Moodle STACK. The rationale and prior art are also discussed. The basics on Moodle STACK quiz design is discussed with emphasis on the difference between a math quiz and a circuit theory quiz. Section 3 suggests a circuit schematic randomization, which is specifically needed in the design of a circuit theory e-quiz.

Section 4 introduces the STACK experiments realized by the Author in two circuit theory courses between spring 2017 and spring 2018. The learning results are compared with the results from the previous year, where the assessment was based on traditional paper exams.

2 Background

In the University of Oulu, Finland, basic circuit theory teaching is split into two courses:" Circuit Theory 1" (CT1) and" Circuit Theory 2" (CT2). The courses are lectured by Professor Timo Rahkonen and the Author's responsibility is to conduct the calculation exercises and design the simulation exercises. The Moodle STACK activities were fully realized by the Author.

In the past, both CT1 and CT2 had two-part voluntary partial exams, which were held in the contact-teaching venue. The students were offered a chance to avoid the dreaded final exam by passing more than 50% of the points from both parts.

The impetus to pilot STACK-based assessment in circuit theory came from the good experiences on mathematics courses held in the University of Oulu. As a benefit, circuit theory students were initially familiar with Moodle STACK user interface.

2.1 Circuit Theory 1

Circuit Theory 1 (CT1) is intended for first-year students. The annual number of students enrolled in the course is around 90. The annual training program intake at the Department of Electrical Engineering in the Faculty of Electrical and Information Engineering (ITEE) is around 50 students. For other students from different departments in ITEE or faculties, CT1 is optional. For the 50 electrical engineering students, CT1 is one of their first intermediate studies with five credits (ECTS standard). The required background knowledge contains the math courses prior to CT1. CT1 consists of the following themes:

- Introduction and basic laws
- Circuit analysis techniques for resistive networks
- Impulse- and step-response to a simple RC- or RL-circuit
- Sinusoidal steady-state analysis and phasor power calculation

2.2 Circuit Theory 2

The extent of CT2 is also 5 credits. Continuing after the summer break, the target group is mainly 50 students from the Department of Electrical Engineering. CT1 is the required background knowledge and the topics covered in CT2 are:

- Laplace-transform in circuit analysis
- Transfer functions and pole-zero maps
- Bode diagrams and stability
- Two-port circuits

2.3 Learning Difficulties in Circuit Theory

As witnessed by the Author and the Professor, the typical learning difficulties in CT1 agree well with paper by Bernhard and Carstensen in [9]: in the subject of basic laws and forming equations, the typical problem is the lack of conceptual understanding, e.g. problems distinguishing the difference between voltages and currents. In the subject of transient response and phasor calculus, many students struggle with applying the lessons learned in the earlier math courses (on differential equations and complex analysis). With a barely passed CT1 exam, the problems will be reflected in CT2.

McDermott and Shaffer published a two-part publication that delves into two questions: "What are the most often misunderstood concepts" [10] and "What is the instructional strategy for underlining these concepts?" [11]. Related to these topics, P. Engelhardt [12] created a reliable tick-box assessment template. Here, an e-exam that clarifies the concepts was realized for CT1 (see Sect. 4.3). The quizzes in the e-exam were mostly computational with few tick-box questions.

In Mujtaba's study [13], it was found that success in binary or computational problems do not correlate well with the success in descriptive problems. The reason may be at least partially explained in Bolhuis's work on process-oriented learning [14] students differ in their learning skills and self-management capacity as well as in tolerance of uncertainty. The lack of descriptive problems in an automated e-exam can be compensated by encouraging the students to ask questions in e-forums and providing dedicated teacher-led PC-classrooms sessions.

The learning difficulties should be addressed without disrupting the progress of more advanced students. The time in which misconceptions are formed is roughly at the beginning of an elementary circuit theory course. It would therefore be prudent to conduct an introductory circuit theory exam at the beginning of CT1 (see Sect. 4.3). On the other hand, the success in CT2 requires CT1-skills that can be recapitulated by a placement test.

3 Circuit Theory E-Quiz in Moodle STACK

We will begin this Section by explaining the rationale on choosing STACK in the circuit theory courses. Section 3.2 describes the structure of a single STACK quiz and Section 3.3 discusses randomization specifically for a circuit theory e-quiz.

3.1 Why Moodle STACK?

As examples of prior art, recent publications on circuit theory e-learning solutions by Weyten *et al*. (2009) [15], Skromme *et al*. (2015) [16] and by DePiero *et al*. (2016) [17] focus in topics on introductory linear circuit analysis such as basic laws and theorems, equivalent circuits, nodal analysis, mesh analysis, superposition, DC-analysis and AC-analysis. These topics cover roughly 75% of Circuit Theory 1.

The problem in many documented e-tools can be difficult to access, evaluate and modify. This brings out the major advantage of Moodle: The” ecosystem”, is free (no license fees), well-established, widely translated (over 100 different languages) and accessible in most countries. With the help of 1000+ plugins available (such as STACK), there is no feature or pedagogic approach that cannot be implemented in Moodle. Moreover, Moodle enables sharing and customizing the quiz among teachers. Creating a multilingual quiz is also a built-in feature, which is often required in non-English institutions with foreign exchange students.

Throughout the world, there are several non-STACK circuit theory courses established in Moodle. A noteworthy publication by Barroso *et al*. [18] documented a circuit theory based competitive learning game at the University of Valladolid, Spain. Here, students were divided into groups and competed in a tournament through a series of knockout rounds. The games were conducted in a teacher-led physical classroom and the Moodle questions were enhanced with electronic blackboard and Java applets.

3.2 The Basics of STACK Quiz Design

To briefly summarize the structure of a single quiz, the main three parts are

- Question Variables
- Question Text
- Response Tree

Question Variables contain teacher-defined functions, equations, expressions, parameter randomization, model answers and conditioning rules. Conditioning rules are also connected with the deep level of quiz randomization discussed in Section 3.3.

Question Text is a sheet in HTML format with rich text, equations in LATEX-format, student answer inputs, videos, static figures (e.g. JPEG) and Maxima-generated graphics. It also includes answer validation, which enables the student to see how Maxima has interpreted the answer. The Question Text can be edited as HTML code, which enables embedding applets and creating multilingual questions.

A traditional paper exam has the advantage that is hard to match: the answer has no predefined structure and the point rewarding is performed by a human expert. STACK has an inherent ’penalty scheme’ that can equivalently spread the point histogram between students. The default penalty scheme subtracts e.g. 10% of the marks for each incorrect attempt, and this scheme has been found to reward persistence and diligence [3]. The existence of a penalty scheme forces the student to limit the number of checks to the minimum.

The actual assessment and feedback are programmed in the Response Tree, which has an important role in guiding the student through a quiz. A single question within a quiz may contain one or more answers which is assessed in one Response Tree. The Response Tree allows creating an acyclic directed graph [3] that enables partial point rewards and customized feedback. In other words, the Response Tree can pinpoint the quality and quantity of the mistake and guide the student accordingly. Moreover, the default penalty scheme can be overridden or discarded in the response tree. The feedback to the student can be textual (with numbers or math expressions), graphical or even an embedded video. For instance, comparing graphical frequency responses from correct and student answers can sometimes be the best way to guide the student.

An important point in designing student assessment in STACK is that it can be realized badly either in the quiz level or in the chosen exam preferences. In case of insufficient automatic feedback, a student may be stuck on a quiz due to a minor typographical error. On the other hand, a well-designed bundle of quizzes may be ruined by a poor choice of exam preferences, such as tight execution time or harsh penalty strategy. An example of bad exam preferences is documented in Section 4.1.

3.3 Randomizing a Circuit Theory Quiz

For a take-home e-activity with potential impact on the grade, it is imperative to design questions that vary amongst students. Parameter level variation in Question Variables is a built-in feature, but this may not be enough in a circuit theory quiz. The essential part of a circuit analysis quiz is typically a circuit schematic.

In a typical mathematics-quiz, there is no need to randomize static images, which makes it easy to implement tens of quizzes. Reusing a circuit theory quiz annually requires more work, as the quiz should contain several alternative schematics (static images).

A quiz is basically a file that can contain an embedded pool of static figures (e.g. in JPEG format). The figure visible to the student can be randomized just as easily as randomizing variables. The principle is shown in Fig. 1. A random integer in Question Variables determines the choice model answer and the JPEG file shown in Question Text. In Fig. 1a, Question variables contain all N variations of model answers. From N variations, the correct one (n^{th}) is selected by conditioning rules (if-then-else). Furthermore, the random variations in circuit elements (e.g. resistances and capacitances) are randomized. Question Text in Fig. 1b displays the nth schematic and prompts for the student's answers {ans1, ans2} accordingly. To display the randomized a static JPEG/PNG image requires modifying the HTML code in the Question Text. Detailed instructions have been uploaded to Abacus [19] database by the Author.

The response tree in Fig. 1c is an acyclic directed graph [3] that contains the assessment test nodes with point rewards, point penalties and feedback. In Fig. 1b, the quiz prompts the answers to symbolic equation (ans1) and numerical expression (ans2). In the response tree, the symbolic equation in ans1 is compared with the model answer Tans1 (for the nth schematic) in an algebraic equivalence test in the node test1. If it fails, test11 finds whether the equation has all the necessary symbolic variables. If the result is true (yes), the node displays feedback, e.g." pay attention to sign errors". If test11 fails, the feedback displays the missing or unwanted variables and stops. The quiz designer can modify the Response Tree in Fig. 1c with ease. For instance, the output nodes of test11 can be both 'stop', indicating that the second student answer (ans2) will not be assessed if the first (ans1) is incorrect.

In circuit theory, the numerical answer is rarely an integer. The numerical expression ans2 assumes floating point coefficients. Here, the expression ans2 is evaluated at a certain time t = T by STACK and compared with the correct answer Tans2 with a certain error margin (typically 5-10% relative error).

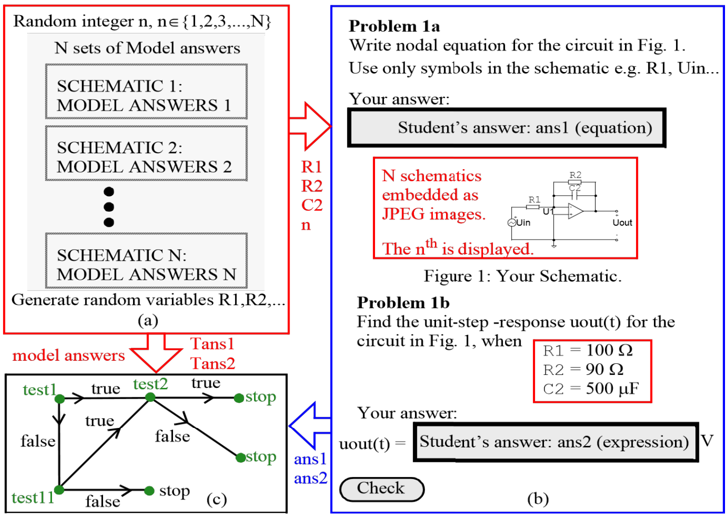

Fig. 1. A STACK quiz: a) Question Variables, b) Question Text and c) Response Tree (the acyclic directed graph).

In a circuit theory quiz, there are other randomization tricks suited for a single circuit schematic, where the randomization is shown in the Question Tree text:

- Randomizing switch position (e.g. position 1 or position 2).
- Randomizing the control type (voltage or current) of a controlled source.

The switch position randomization was used in a CT1 e-exam (Subsect. 4.1). The control type randomization is feasible and simple to realize, but so far it has not been realized by the Author as it can easily lead to question variants with unequal levels of complexity.

4 Realized Circuit Theory E-Activities in Moodle STACK

For several years, the students in CT1 and CT2 were able to obtain a grade by passing two voluntary paper-exams held in classrooms. These exams, executed in the teacher's presence, were half-exams with a 90-minute execution time each. To pass the course, 50% of the points were required for both voluntary exams.

4.1 Spring 2017 - Circuit Theory 1

In the spring of 2017, two voluntary paper exams were transformed to seven take-home e-exams. The exams were split into two parts with equal point weight. The course lasted for seven weeks and the e-exams were weekly. Compared with the traditional 3-hour final exam, the weekly exams had a total of 50% more calculation and twice the time to perform.

According to several pedagogic publications (discussed and listed in [8]), students appreciate online homework in mathematics courses. According to the turnout in CT1 e-exams 2017, the appreciation is not restricted to mathematics.

In 2016, 57 students partook the traditional 2-part paper exams. In 2017 e-exams, the turnout was staggering: 105 students. This means that practically all potential students partook the e-exams. As an approximate, 65 were from the department of Electrical Engineering: around 50 first-year students and 15 older students who had not passed the course. The rest of the students (around 40) had CT1 as an optional course.

For the spring of 2016, the grade histogram is shown in Fig. 2a. Here, the best grade is 5. Fig 2a also shows the passing after the traditional final exam. From the seven e-exams in 2017, the grade histograms on the number of passed students are shown in Fig. 2b. Comparing the absolute number of best grades in Fig. 2, the e-exams were relatively harder that the 2-part exams in 2016. After final exams, medians for 2016 and 2017 were 2.5 and 2.0, respectively. The rejection ratios in 2016 and 2017 were virtually identical between 2016 and 2017: 38.5% and 38.0%, respectively.

The general complaint with these e-exams was the lack of time. Even though the level of difficulty versus execution time was carefully considered, most students found the time limitation extremely stressful. The main flaw in the realization was that the Author did not consider the fact that the execution of a STACK e-exam and a regular exam are very different. The students received the programmed feedback, but the majority did not have enough time to learn from mistakes. As a clear conclusion: the execution time was unfair to most.

In their feedback on the e-exam experience, students preferred STACK e-exam in the form they were accustomed to in prior math courses: auto-assessed homework with some point-reward and plenty of time.

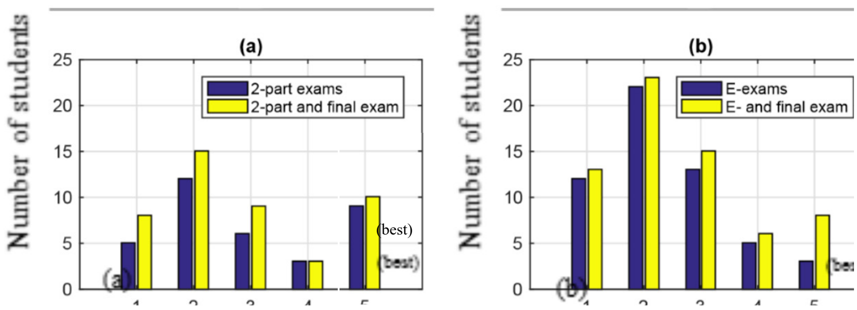

Fig. 2. The Grade histograms of the passed students in a) 2016 and b) 2017.

For any non-invigilated take-home e-exam, there is always the possibility of cheating. As the quizzed were well-randomized, there was no chance to copy a friend's answer directly. However, there was flexibility in the exam timing i.e. the starting moment had a few-day window.

Here, the bad choice of exam preferences probably inspired some students to bend the rules. The Author's suspicion was aroused by browsing through the students' individual execution times. Some e-exams were executed very quickly e.g. a 60-minute e-exam in 5 minutes. After some oral interviews, it was found that this was a systematic approach to a large group of students. Together, they compiled a template from which the easiest answers were quickly prompted.

As an estimate, some 30% of the students were engaged in solving the problems as a group. This could be a reason to disqualify all e-exam results, but there are mitigating facts:

- It was clear for both teachers and the students that the e-exams are not invigilated.
- Spontaneous learning in groups were most likely beneficial to learning.
- The rejection ratio indicates that passing required learning.

Due to the bad experience, the implementation of the following Moodle STACK e-activities in Circuit Theory 2 (Sect. 4.2) was much like in the mathematics courses in the university of Oulu. To address students' inherent tendency to group activities, there were some teacher-organized PC-class sessions dedicated to the e-activities.

4.2 Fall 2017 - Circuit Theory 2

In the fall of 2017, the partial paper exams were omitted, and a preliminary e-exam was launched in Circuit Theory 2 (CT2). Here, the well-tried properties of the STACK-enhanced math-courses in the University of Oulu were applied:

- The points from the e-exam can improve the grade.
- The students were able to answer the quizzes during the course.
- The e-exam can be retried, and the best attempt will be considered.

Unlike in the math-courses, CT2 preliminary had a precondition: the points improved the grade only if the traditional final exam was passed. The preliminary e-exam for CT2 was realized as bilingual (Finnish/English) and it can be evaluated and downloaded from Abacus database [19].

The e-exam contained four quizzes, representing each of the main CT2 topics listed in Sect. 2.2. The difficulty of the e-exam was similar to the final exam. The 10% penalty scheme (Sect. 3.2) was used. After finishing the preliminary exam, the student received useful tips and some correct answers. Due to schematic and parametric randomization (Sect. 3.3), the displayed answers were useful for learning but not as a crib sheet for the next attempt.

As mentioned in Section 3.1, Moodle can be used to create meaningful collaboration activities such as Barroso's game [18]. The preliminary exam in CT2 was no group effort per se, but the students were encouraged to learn together. For this purpose, a PCworkstation was reserved four times during the course. As the preliminary exams were deeply randomized, the students saw many versions.

Let's compare the results from 2016 and 2017. The features of the final exams (traditional paper exam) were much alike in 2016 and 2017:

- Four questions with a maximum of 3 points each (12 points total).
- At least 50% of the points were required from the first and last two questions.

In 2016, the voluntary paper-exams were equal to the first and last half of the final exam with the 50% requirement. Students had the freedom to improve the one of the voluntary exercises in the final exam. The ones that did not partake in the voluntary exams, did the final exams as a normal exam. 36 students partook the examinations in 2016.

In 2017, the maximum points from the preliminary e-exam were two. The grading system was therefore shifted with the point maximum increase from 12 to 14 points. The best grade of 5 was still obtainable with just the final exam. The minimum requirement for passing i.e. the 3p+3p final exam criterion remained from last year. In 2017, 41 students partook both the final exam and the preliminary.

Grade distributions in 2016 and 2017 are shown in Fig. 3a. According to the statistics, the results were quite similar: the average and standard deviation of grades were {2.25,2.05} in 2016 and {2.27,2.03} in 2017. The passing ratios in 2016 and 2017 were 64% and 61%, respectively.

Regardless of the striking statistical similarity, there are factors that favour choosing the preliminary e-exam. According to personal conversations and a survey conducted after the course, the following features favour the e-preliminary:

- Students prefer e-activities and the freedom in scheduling their performance.
- A seven-week preliminary can be formative (progress within a given time window).
- The preliminary e-exam generates study groups spontaneously.

The different grading systems in 2016 and 2017 are compared in Fig. 3b. The points of the exam in 2017 is here converted to grades using the 2016 grading system (horizontal axis) and the 2017 grading system (vertical axis). In 2016, it was easier to obtain grades 2-5, but the passed students in 2017 were successful in the preliminary exam: 56% of the passed improved their grade due to the preliminary exam.

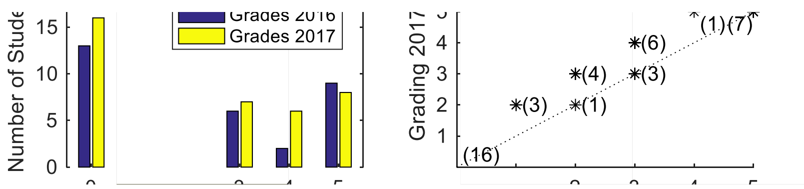

Fig. 3. CT2 grading comparison: a) grade histograms and b) grading system comparison using the points from the final exam in 2017 (the number of students in parentheses).

Let's have a critical look at the preliminary e-exam as a learning experience. The statistics of preliminary exam results are displayed for each question in Fig. 4. Each box plot in Fig. 4 display variation in samples of a statistical population without making any assumptions of the underlying statistical distribution. The bottom and top of the box are the first and third quartiles (a measure of statistical dispersion, being equal to the difference between 75th and 25th percentiles). The middle thick line represents is the median.

Clearly, the students who passed the exam (Fig. 4a) gained a high score from the preliminary exam. For the failed (Fig. 4b), the large dispersion indicates that the latter questions in the preliminary were more challenging for the failed. A classic p-value test for the passed and the failed separately suggests there is no statistical relationship between the final and the preliminary exam success.

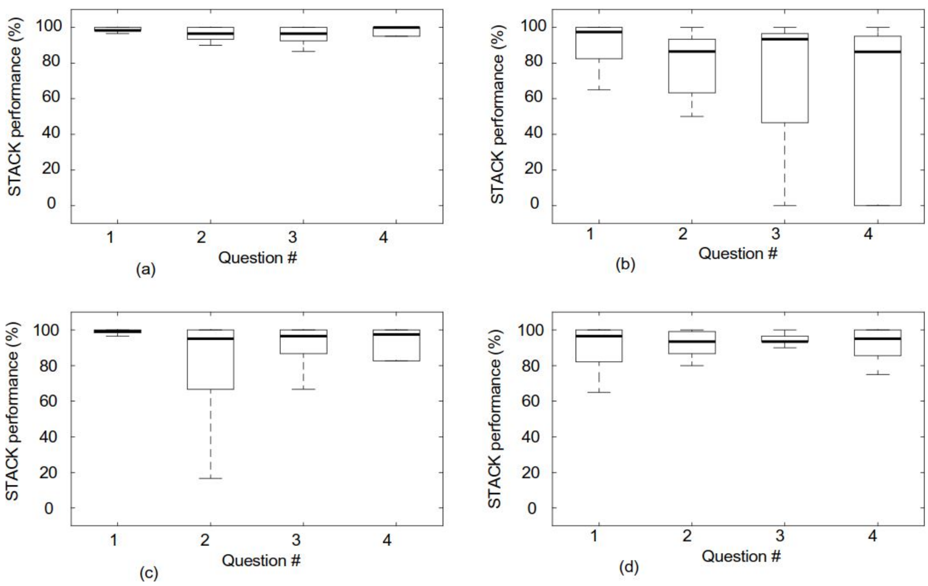

Fig. 4. Boxplot of the preliminary e-exam performance for a) the passed (N=25), b) the failed (N=16), c) 'honest' (N=26) and d)'less-honest' (N=15) students.

To statistically separate the students by relative honesty, the following test was performed. The point-based results from the preliminary and the final exams were normalized and the students whose preliminary exam went more than 1.6 times better labelled as 'less honest'.

Surprisingly, separating the 'honest' and 'less-honest' revealed a significant correlation: the p-values were smaller than the typical significance level of 0.05. For the honest students only, the p-value is $1.66 \cdot 10^{-5}$ and the Pearson correlation coefficient is 0.74. For the less-honest, the p-value and the correlation coefficient are 0.017 and 0.61, respectively. In the honesty-based separation, there were four passed but less-honest students and five failed but honest students.

The boxplots in Fig. 4c and 4d reveal the preliminary exam success statistics for the honest and less-honest, respectively. This is useful data in developing the preliminary exam. For instance, the honest students in Fig. 4c found the Laplace-transformation in Question 1 very easy. The Bode diagram quiz in Question 3 was successful for the less-honest in Fig. 4d. To speculate the reasons, perhaps the random variations Question 3 had the clearest pattern and a solutions manual was conjured.

As shown in Fig. 3b, the total of 16 students failed the final exam. From the 16, 10 students had a good (1.5 to 2 point) score from the preliminary exam. In the following survey, the students were asked why many failed students did so well in the preliminary. The answers contained two interesting angles. The first suggests that some students are diligent in the art of scoring points: “With no pressure on the execution time and the chance to retry, there is no connection between the performances between the two. With enough diligence, anyone could have scored full points from the preliminary exam.”

The second angle offers an important perspective: “Perhaps some thought that taking the preliminary exam is enough preparation to the final exam.” Indeed, some students do not perceive their lack of skills until after the final exam.

The purpose of the preliminary exam was to improve knowledge and thus help students to pass the final exam. According to the statistics, the students who shared this view were likely to pass the final exam. The precondition to pass the final exam alleviates the arms race: there is no need to add layers of randomization just for the sake of less-honest students.

In any field, there should be means to support the weak (and often silent) learners. In CT2, some students stumble with the required previous knowledge on CT1. A placement test at the beginning of the course would recapitulate the CT1 skills required. In the fall 2018, Circuit Theory 2 will continue using preliminary e-exam. As a new item, the placement test recapitulating CT1 will be realized as a mandatory e-activity.

4.3 Spring 2018 - Circuit Theory 1

In the spring of 2018 there were many e-activities for CT1. To avoid excessive strain, some activities had to be voluntary. The most important compromise was choosing between a placement test and an introductory exam. The former recapitulates the math needed in CT1 and the latter concentrates on clarifying the most common misconceptions in elementary circuit theory. The Author chose the introductory exam since the misconceptions are hard to patch after the course.

The mandatory simulation exercise was realized in Moodle STACK for the first time. The simulation exercise required passing the introductory exam as a prerequisite.

Planning e-activities requires estimating the student’s work load. Here, the median time to perform compulsory activities was around 30 hours, which was close to the targeted 27 hours (around 1 credit unit work load).

The introductory exam and the simulation exercises has been uploaded to Abacus [19] database.

Placement Test: In general, the function of e-learning tools is to activate students and perform continual assessments. At the beginning of a course, it is often prudent to test and awaken the students’ prior knowledge. As CT1 requires the skills to solve differential equations and perform phasor calculus, it should be recapitulated at the very beginning.

The goal for the placement test in CT1 was to effectively address student's initial skills. A placement test may help a weaker student to identify and improve his/her incoming skills. The CT1 placement test also contained entertaining circuit theory introductions with an experimental angle. This way, the students with weaker learning skills may be more motivated to patch their initial skills.

The voluntary placement test in CT1 did not affect grades. It was introduced as a challenge that can be retried as many times as possible. Unfortunately, the placement test was not lucrative. Out of 69 students who were active in Moodle, only 23 participated and only four students did the whole placement test.

Introductory Exam: The compulsory introductory e-exam needed to be passed before performing the simulation exercises. This e-exam concentrated on the important basics if circuit theory taught at the first two lectures. The pedagogic idea was to underline the common misconception in circuit theory discussed in Section 2.3 and [9]-[13]. Automated Moodle STACK assessment cannot cover descriptive problems [13] with essay-type inputs, but the students were had the chance to discuss the problems via Moodle forums and in person. The intro exam had six questions and passing the intro exam required at least 75% of the points. The exam had no point penalty or restrictions in the number of retries. Out of 69 participants, 60 students passed the introductory exam.

The introductory exam was graded as either pass or fail. Statistics on the introductory exam revealed only the obvious: the students who passed the final exam seemed to be keener on getting the maximum points from the introductory exam.

Simulation Exercises: CT1 has always contained compulsory circuit simulator exercises. These exercises are conducted with the circuit simulator LTspice [20] and graded as pass or fail. In the past, the simulator exercises were assessed manually. In spring 2018, they were assessed by Moodle STACK for the first time. The exercise themes were in-line with the four main themes listed in Sect. 2.1. The exercise was split into two parts.

In the simulation e-exercise, the student returned the answers to the simulation problems. With the help of STACK, the parameters and some schematics were randomized, and the answers were automatically assessed. Penalties from wrong answers were disabled, but all answers were needed to be correct. After answering, the student copy-pasted a textual netlist from the simulator. The netlist was assessed manually, and it ensured that the student used the simulator.

The total of 41 students passed both parts of the simulation exercise, which is a surprisingly small number knowing that 60 passed the intro exam. Out of 41, there was only one student that needed to re-perform some simulations.

Support for the simulation problems was be given by dedicated PC-classroom sessions and an online-forum. According to the survey conducted after the course, both were found very helpful and 39% of the students relied on peer-support such as asking a fellow student or performing the simulations together.

Preliminary Exam: In the spring of 2018, CT1 preliminary e-exam was a voluntary activity without reward. As the Authors resources were depleted on designing the intro exam and the simulation work, the questions were mostly recycled from 2017 (Sect, 4.1). The turnout was quite disappointing: only six students attended. This (and the turnout in the placement test) proves that the average freshman is not willing to perform e-exercises with no direct reward.

Final Results and Some Thoughts: In the CT1 survey, the students assessed the difficulty of the introductory exam and both parts of the simulation exercise in the scale of 1 (easy) to 5 (very hard): 2.3, 2.8 and 3.3. In words, the difficulty level was adequate. As a learning experience, the assessment was also from 1 (did not learn anything) to 5 (very educational). The results for the introductory exam and both parts of the simulation exercise were 3.7, 4.0 and 3.9, which is quite assuring.

As mentioned, the work load on mandatory Moodle STACK tasks was well-designed. According to the survey and personal conversations, many students struggled with the work load related to external reasons: compulsory language-course and retaking math-exams. The total of 53 students partook the final exam, 47 of which were active in Moodle STACK. Only 27 students passed the course by the time CT2 begun in the fall of 2018.

5 Conclusion

STACK is a crucial Moodle plugin for realizing e-pedagogy for any discipline that can benefit from the capability of evaluating and assessing mathematical answers. This study documented the realization of two circuit theory exams in Moodle STACK. The environment was found very versatile and flexible for automated circuit theory assessment.

This work also points out that STACK enables question randomization at many levels. This is particularly important in circuit theory, where the foundation of all calculation is typically a circuit schematic. For a take-home e-exam that effects on the grades or passing the course, it should be a default practice to scramble the schematics within a quiz.

Another important lesson learned in realizing circuit theory quiz in Moodle STACK is the philosophical difference between a paper exam and a STACK e-exam. A STACK quiz strives for finding the correct answer through student feedback, and this requires more time. Moreover, it was also found that take-home e-activities benefit from a dedicated, teacher-led support such as PC-class sessions and e-forums.

In 2017, a preliminary e-exam in Circuit Theory 2 had a 7-week execution time and it was truly successful and well-liked by the students. As a learning tool, the preliminary e-exam with the precondition of passing the traditional final exam was the most successful e-activity realized in this work. It was found that there is clear correlation between the success in preliminary and final exam, if the student perceives the preliminary exam as a learning instrument.

In 2018, Circuit Theory 1 course concentrated on further expanding the palette of e-activities. The mandatory simulation exercise was realized in the Moodle STACK for the first time. The exercise was connected to a compulsory introduction e-exam, whose purpose was to ensure that the students obtained the initial skills and concepts required in circuit simulations.

CT2 preliminary e-exam (2017) along with CT1 intro exam and simulation exercises (2018) can be evaluated and downloaded from Abacus [19], a Finnish material bank for STEM education.

6 Acknowledgement

This work was supported in the University of Oulu by Faculty of Information Technology and Electrical Engineering (ITEE) strategic funding: "Using Moodle Stack in EE Courses" and "Circuit Theory Kickstarter".

7 References

[1] Moodle.org, *The Moodle Project*, Available: https://moodle.org

[2] C. J. Sangwin, “Assessing mathematics automatically using computer algebra and the internet,” *Teaching Mathematics and its Applications*, vol. 23, no. 1, pp. 1–14, Mar. 2004. https://doi.org/10.1093/teamat/23.1.1

[3] C. J. Sangwin,” STACK: Making many fine judgements rapidly,” in Proc. CAME 2007, Symposium of Computer Algebra in Mathematics Education, pp. 1-15, 2007.

[4] Maxima.sourceforge.net, *Maxima, A Computer Algebra System*. Available: http://maxima.sourceforge.net

[5] A. Rasila, M. Harjula, and K. Zenger,” Automatic assessment of mathematics exercises: Experiences and future prospects,” in Proc. ReflekTori 2007: Symposium of Engineering Education. Helsinki University of Technology, Finland, Teaching and Learning Development Unit, pp. 70-80, 2007.

[6] E. R. Cerval-Penã,” Automated computer-aided formative assessment with ordinary differential equations,” Master’s thesis, University of Birmingham, 2008.

[7] J. Ruokokoski,” Automatic assessment in university-level mathematics,” M. Sc. thesis, Helsinki University of Technology, 2009.

[8] M. Vasko, S. Ritter, and G. Metzger, “Online homework in engineering mathematics: Can we narrow the performance gap?”, *International Journal of Engineering Pedagogy (iJEP)*, vol. 8, no. 1, p. 29, Feb. 2018. https://doi.org/10.3991/ijep.v8i1.7526

[9] J. Bernhard and A.-K. Carstensen,” Learning and teaching electrical circuit theory,” in Proc. Physics Teaching in engineering education, pp. 163-178, Jun. 2002.

[10] L. C. McDermott and P. S. Shaffer, ‘Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding’, *American Journal of Physics*, vol. 60, no. 11, pp. 994–1003, Nov. 1992. https://doi.org/10.1119/1.17003

[11] P. S. Shaffer and L. C. McDermott, ‘Research as a guide for curriculum development: An example from introductory electricity. Part II: Design of instructional strategies’, *American Journal of Physics,* vol. 60, no. 11, pp. 1003–1013, Nov. 1992. https://doi.org/10.1119/1.16979

[12] P. V. Engelhardt and R. J. Beichner, ‘Students’ understanding of direct current resistive electrical circuits’, *American Journal of Physics*, vol. 72, no. 1, pp. 98–115, Jan. 2004. https://doi.org/10.1119/1.1614813

[13] A. H. Mujtaba, 'Analyzing student conceptual understanding of resistor networks using binary, descriptive, and computational questions', *American Journal of Physics*, vol. 86, no. 2, pp. 146–152, Feb. 2018. https://doi.org/10.1119/1.5008266
[14] S. Bolhuis, 'Towards process-oriented teaching for self-directed lifelong learning: a multidimensional perspective', *Learning and Instruction*, vol. 13, no. 3, pp. 327–347, Jun. 2003. https://doi.org/10.1016/S0959-4752(02)00008-7
[15] L. Weyten, P. Rombouts, and J. De Maeyer, 'Web-Based trainer for electrical circuit analysis', *IEEE Transactions on Education*, vol. 52, no. 1, pp. 185–189, Feb. 2009. https://doi.org/10.1109/TE.2008.924213
[16] B. J. Skromme et al., 'Computer-aided instruction for introductory linear circuit analysis', in 2013 IEEE Frontiers in Education Conference (FIE), 2013.
[17] F. W. DePiero, K. C. McKell and B. Benson," CATE: A circuit analysis tool for education" in Proc. ASEE 123rd Annual Conference & Exposition. New Orleans, LA, 2013.
[18] R. J. D. Barroso et al., 'Competitive learning in electric circuit theory using MOODLE', in Organizational, Business, and Technological Aspects of the Knowledge Society, Springer Berlin Heidelberg, 2010, pp. 113–122. https://doi.org/10.1007/978-3-642-16324-1_13
[19] A. Rasila (coordinator)" Abacus, a material bank for STEM education," [Online]. Available: https://abacus.aalto.fi/
[20] Analog Devices, *LTspice*. Available: http://www.analog.com/en/design-center.html

8 Author

Marko Neitola is a post-doctoral researcher in the University of Oulu, Faculty of Information Technology and Electrical Engineering (ITEE), Circuit and Systems Group (CAS), P.O. Box 4500, 90014 University of Oulu. Currently, he teaches in three courses: Circuit Theory 1-2 and Analog filters. He has also been involved in tutoring doctoral students. His post-doctoral research interests are linearization techniques for data converters and amplifiers.

Article submitted 20 June 2018. Resubmitted 09 October 2018. Final acceptance 10 October 2018. Final version published as submitted by the author.