Conceptual Learning of Electric and Electronic Circuits With Gamification

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Abstract
In recent years there has been major growth in the use of gamification in education. It can be utilized to develop assignments or learning environments. Lots of studies have already proven the positive impact of introducing such tools to students. This paper examines how gamification techniques can be used in the electrical engineering course. It describes the developed tool, future opportunities and possible extensions. The *CLR: Current Surf* is a nice illustration of combining visualizations with game elements to create highly motivating learning environments. It provides students with a choice of a way of exploring new material: active learning by interacting with a visualization tool, which helps to simulate the altering of circuit's components values, or learning new concepts while passing levels in the gamified environment. Future steps of the project will include the evaluation and gathering students' feedback.

Author Keywords
gamification; innovative engineering education; conceptual understanding; students' motivation;

CCS Concepts
•Applied computing → **Interactive learning environments; •Human-centered computing** → *Visualization toolkits;* **•Theory of computation** → *Convergence and learning in games;*

Introduction

Gamification is the application of game elements in non-gaming contexts [6]. Using gamification for educational purposes is gaining more popularity in recent years. There still is a lack of research regarding the application of gamification in higher education specifically. But this question is getting more attention recently, and examples can be found in [7, 12, 22].

This paper focuses on the application of gamification for enhancing electrical engineering education. One of the basic courses is dedicated to the study of electric (linear) circuits and electronic (non-linear) circuits. The classic approach is to start from the basic laws that apply to these circuits, such as Kirchhoff's Laws, and their basic components, such as sources, resistors, capacitors, and diodes. Analysis of these circuits includes the derivation of a set of equations and finding the solution by solving these equations. While it is important for future engineers to have the skills to perform these actions, this approach does not guarantee that students gain a conceptual understanding of the basic processes in such circuits. E.g. predicting the behavior of a circuit when a component is modified, without deriving the mathematical equations, is also an important skill for future electrical engineers. In order to help students to gain such a conceptual understanding of the topic, it was suggested to create a tool which simulates the behavior of the circuit. Values of the components can be increased or decreased by students, and the changes are reflected immediately on the simulated circuit. This can lead to a better understanding of the influence of specific components metrics to the general circuit parameters. A detailed explanation of the simulation principles can be found in the next sections.

In this project, the first step was a review of existing literature and related work. Results are discussed in the following section. Afterward, novel ways of visualizing the phenomena that occur in electric and electronic circuits have been investigated. The next step, which is mostly discussed in this article, is adding gamification to the educational tool. The main goal of the project is to help the students to gain a better conceptual understanding of the circuits and increase their motivation to use the tool more extensively. Description of the future steps and possible extensions of the project is followed by the discussion on the achieved results.

Gamification in education

Gamification in education has proven to increase students' motivation [10, 19] and interest in course [23], improve learning outcomes [20], assist students to develop problem-solving skills [13]. Other aspects of education which might be improved by gamification are described in [18]. Game-based learning shouldn't necessarily be digital only. It might be in the form of a board game, for example for teaching the principles of quantum computing [25]. Or in the form of a card game for learning the pragmatics of second language [15].

There is an ongoing discussion of a difference between a serious game and a gamification [14]. By definition, *serious game* is a game that has non-entertainment purposes such as education or training [16]. But at its core, it still remains a game rather than a tool with added game elements, such as progress bars, points, levels, etc. Since this distinguish is quite vague, there have been some attempts to formalize the difference. For example, [9] discusses the following gamification constraints relevant to the current project:

- *not a complete game*, so that gamification elements are attached to some real activity or tool, even when the result might be perceived as a game;

- *not primarily for entertainment*, but aimed to engage users in achieving non-game related goals;

The interactive tool with a sole purpose of visualization was developed initially, and game elements have been added to it gradually. Even afterward it still kept the visualization functionality, hence we consider it to be a *gamification* example.

Related work

This section provides a brief description of existing researches about the application of gamification in teaching the electronic/electrical circuits theory.

1. *Circuit Warz, the Games [3]*

   This research describes an opportunity for using VR platforms (such as OpenSim) in addition to gamification to enhance education. An example is shown in teaching an advanced electronic/electrical circuit theory, through a game based learning experience in a 3D immersive world. In Circuit Warz, the Games groups of students collaborate and compete against other teams to complete a virtual assault course, which is in practice a series of electronic and electrical circuits (puzzles) which need to be solved (i.e. biased correctly). Students provided positive feedback about the collaboration and teamwork possibilities, and academical stuff liked the approach too. But no real evaluation has been made. The next stage of this research is *Circuit Warz: a serious game [4]*. But it is already taken beyond the concept of gamification and transferred to a serious game [2]. The game includes seven different circuits, varying in difficulty. A player has to select a required element from a provided store in order to create a correct combination for needed output. The research contains a very detailed mapping of game mechanics to relevant learning mechanics and the reasons for introducing specific game elements to serious educational games.

2. *A gamified framework to motivate students: TESLA [24]*

   This is not a particular app but rather a generic framework used to motivate engineering students. The goal of the game used in it is to construct a wireless charger for an electrical vehicle from its pieces, such as diodes, capacitors and etc. The research introduce a theoretical students' knowledge check before they can get access to the next level. And each level increases the difficulty of used elements. All levels are connected with a generic goal - building the charger step by step. Also, the paper has a detailed description of learning outcomes' evaluations and questionnaires which can be used to research the impact of gamification in education.

3. *Minecircuits: a serious game [26]*

   This is one more example of a serious game aimed to teach the digital circuits. In it, players gain scores and pass levels by finishing tasks such as completing and finding errors in circuits. The paper lacks a description of single levels and tasks.

Apart from academic research there also are several commercial attempts to do a similar thing. E.g., RedstoneChips plugin for Minecraft game [8] makes it possible to build custom circuits in the Minecraft game world.

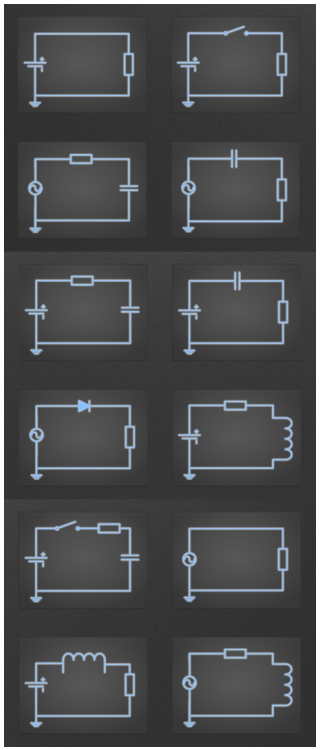

Figure 1: Schemes for some of the circuits presented in the interactive tool

The main difference of this research from the aforementioned papers is that the goal is to create a platform which enables to measure the implications of introducing gamification. This will be achieved by comparing the difference in the learning outcomes of students who used the regular tool, and those who used the gamified one.

CLR - a tool for conceptual understanding of electric and electronic circuits

The tool consists of two parts: an interactive visualization tool and a gamified assignment. Students have a choice with which one they want to proceed. The main goal of both parts is to help students to get a better conceptual understanding of the circuits. However, they use different approaches: active learning by experimenting with the values of the components and seeing the immediate influence of the change; and solving the specific tasks to get the needed values in the gamified assignment. This section describes the first approach, and the gamified tool is described in the next section.

The part with 3D visualizations currently has 15 different circuits in it (Figure 1). Example of a circuit is on Figure 2. All sliders on the left are interactive so that students can change the values of the elements of the circuit, and see the impact of the change immediately simulated. The voltage is visualized as the altitude of a node in a 3D plane, and the current as moving particles through the conductors. Possible values which can be changed include: voltage of a DC-source, AC-source amplitude and frequency, resistors' resistance, the capacity of a capacitor, inductor's inductance, the position of a switch. Relevant inputs are generated each time a circuit is opened, based on the elements presented in a circuit. Amperemeter in the left bottom corner adjusts the value instantly when the value of some of the elements is changed. Same is also true for the circuit

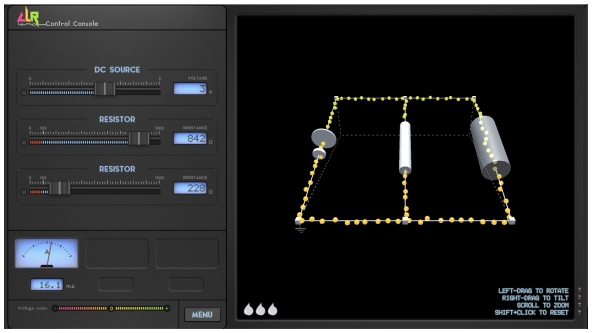

Figure 2: The interface of the circuit simulation, based on the values selected by students.

simulation on the right - it changes immediately to represent the selected values. Changes might be interpreted for example as the position of the switch, speed of the particles or size of the resistors or capacitor.

Current Surf - gamification elements description

Another part of the tool is *Current Surf* - a gamified assignment. It consists of 7 levels with gradually increasing difficulty, based on fundamental electronic and electrical circuits typically found on the first year of engineering education courses. With each level, new elements are added to the circuit, or new elements are becoming interactive.

In order to finish the level successfully it is needed to to set the correct values for all elements so that a game character can "surf" to the next circuit (Figure 6). The target value of the voltage between nodes is shown with the help of a dotted line. The task and the story are displayed to the students in the modal window at the beginning of each level. Then the student needs to guess what values of the components have to be changed in order to get the right volt-

Figure 3: Options for a character's avatar

Figure 4: Points which can be obtained in each level are summarized

Figure 5: Levels roadmap

age. Then they need to click on a character to make it "surf" the current. If the values are correct - the next level starts, and if not - the same one loads. There is an infinite amount of tries for each level. In order to make sure that correct answer wasn't just a guess made by a coincidence, but a demonstration of the conceptual understanding of the relevant processes - each level has three stages. The stages have the circuit with the same elements and the same task, but target and default values are different each time.

In order to increase the potential of this project, there were feedback sessions with the professor of the electrical engineering course in KU Leuven, Belgium. Feedback was given during in-person meetings, together with detailed explanations of expected learning outcomes. The importance of understanding the context in order to build a successful gamified system is well illustrated in [21]. Importance of deep requirement analysis is summarized also in [17].

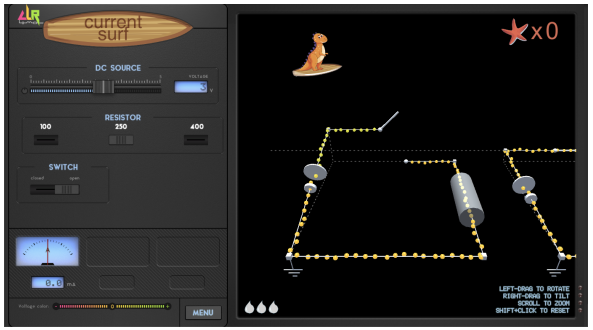

Figure 6: An example of the game level in *Current Surf*

According to [13], four effective game elements are:

- Freedom to fail - is implemented in the current project by encouraging students to make experiments and take risks. A character may die, which will result in fewer points at the end of the level, but the amount of attempts is unlimited.
- Interest curve - in *Current surf* each level is more difficult than the previous one. This helps to keep the students in the state of the flow, and provide interesting challenges while they learn.
- Storytelling - this gamified tool is made meaningful by including a surfing world and avatars on the surfboards (Figure 3).
- Feedback - it is instant after the student clicks on a character to start surfing it rather surfs to the next circuit to indicate success, or falls and dies to indicate wrong selected values. Also, the popup menu with the text confirmation is shown.

Other game elements included in the tool are points, which are awarded for getting the right answer with less tries (Figure 4) and a progress bar which indicates how many correct answers are needed to finish the assignment (in a form of the level map, as shown in Figure 5). Leaderboard and badges are planned as the next step of a project, as additional motivators for the social drive. Game mechanics used in the tool encourage students' active learning by investigating the game world.

Discussions and future development

First sections of the paper show the high interest of the research community in applying gamification to the educational process. Several papers prove that it will increase students' motivation and engagement, but the open question still is how will it influence the learning outcomes. The main difficulty in investigating this question is a need to

Levels description and basic gameplay

Levels 0 - 2: circuit consists of DC source, resistor and a switch. Level 0 is the introductory level, where only the switch should be closed. And in level 2 it is already possible to change the switch position, source voltage and choose needed resistance for a resistor (Figure 6). The idea is to align the "surfing" part of the circuit with the next one so that a character can move between them.

Levels 3 - 6: circuit consists of AC source, switch, resistor and capacitor. This set of levels is more difficult, since because of the AC source "surfing" area is in a constant movement, and it is needed to set up more values.

Target values are random and different each time in order to avoid guessing the right answer.

compare the results of the students in a course or an assignment with and without gamification. That's why a developed tool consists of 2 parts, which serve the same educational purpose, but with different approaches: interactive visualizations and gamified assignment. This will make it easy to run the study about the influence of introducing gamification on the learning outcomes, as mentioned in the previous section.

As pointed out in [5] close attention should be paid to the fact of how students perceive different game elements. For example, the research shows that even though progress bars are an important medium of presenting the current state of the users' progress, students don't find it that useful. That's why in the next phase of the project it is planned to gather feedback from the students and made all required adjustments in order to satisfy the needs of the target users group. Afterward, a study in two universities is planned: KU Leuven, Belgium and Brno University of Technology, Czech Republic. The goal of the planned study is to investigate the following research hypothesis: *[RH1]*: gamification has a positive effect on student's learning motivation; *[RH2]*: gamification in education makes it easier to perceive information and increase learning outcomes. It is planned to have 2 sets of questionnaires: pre-study and post-study, with the same theoretical questions. Comparing the results of the questionnaire for each student will help to understand the difference in knowledge level. Also, it is planned to run sets of questionnaires to measure the perceived usefulness of each part of the tool and compare it with the real one. Examples of such assessments might be found in [11, 1].

The developed tool has a wide possibility for extensions. Some of them are listed below:

- *Data analysis*: multimodal data might be gathered while students' interactions with a tool, such as time to finish the task, amount of wrong attempts, cursor position and etc. Afterward, a prediction of learning outcome can be made.
- *Difficulty adjustment*: in order to keep student's motivated - it is important to keep them in a flow state. And this might be achieved by tailoring the difficulty to each student personally.
- *Dashboards for teachers*: learning dashboards might be used by teachers in order to get a better overview of students' current status.
- *New levels and circuits*.

Conclusion

The main goal for this stage of the project was achieved - a tool for conceptual learning of electric and electronic circuits was developed. The idea is that students need to learn how to perceive the outcomes of changing the values of circuits' elements without making calculations based on formulas. In other words - intuitive understanding of the schemes. Developed tool has two parts: one is for simulation and visualisation of the circuit with the given parameters, and the other is for solving specific tasks in the gamified environment. Having these separate parts creates a possibility to compare the effectiveness of different approaches while presenting the same information to the students. Experiments with the students and gathering their feedback is planned for the next phase of the project.

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