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RESISTANCE IS FUTILE: A NEW COLLABORATIVE LABORATORY GAME BASED LAB TO TEACH BASIC CIRCUIT CONCEPTS

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Abstract

In recent years, gamification of education has proven to be an effective paradigm in modern pedagogy. Following the success their previous work "Sector Vector", the authors now present a new game-based laboratory to highlight the manipulation and calculation of resistors in circuits. In Game of Ohms [1] the lesson of electrical resistance is delivered as an interactive exercise building an intricate circuit. As the game progresses, students are forced to make short and long term plans to modify an evolving circuit which meets primary and secondary objectives (such as total resistance). Each turn of the game requires on-the-fly calculations of resistor combinations in both series and parallel permutations. Students are also exposed to the creation of a modular circuit which does not always conform to standard textbook examples. Together, in an interactive fashion, they must evaluate and analyze a potentially complex overall circuit diagram. The power of disguising the lesson in a game based exercise is examined. Results of student engagement and concept retention have been shown to increase due to the dynamic environment and competitive nature established in the gaming environment. In this paper, we will discuss both the concept of the lab-based game itself, as well as the pedagogical implications of the implementation of this gaming medium versus the traditional resistor combination laboratory exercise.

Keywords

First-Year Undergraduate, Resistance, Resistors. Physics Education, Laboratory Instruction, Interactive
Learning, Physics Pedagogy

Introduction

In most engineering physics programs, basic circuit element analysis is typically introduced in the second semester of a two or three semester physics cycle. When first encountering basic circuits, the concepts of voltage and resistance are introduced using basic circuit diagrams. Aside from typical lecture on the theory of such concepts, the traditional laboratory exercise of placing a few (usually three to five) known resistors in different combinations of series and parallel arrangements is used to demonstrate the underlying resistance addition rules. Although this serves as a good hands on experiment to test the principles of resistance, it often leaves students with very few possible combinations to build in the lab, and does not reflect the innate complexity of even the most basic of modern circuits. Moreover, typically students are disconnected from the theory when using rudimentary laboratory equipment to make fairly simple measurements. Since it has been demonstrated that a more engaged and active approach to physics education has a more lasting effect on the retention of material [2], it was our goal to design a new and exciting way to communicate the concept of resistance. Given our success with "Sector Vector, a new interactive game based lab" [3], we decided to try teaching resistance and combinations of resistors in a new game based laboratory exercise we call “A Game of Ohms”. We expected that a competitive atmosphere would foster mastery of the underlying concepts.

Game of Ohms is a game designed by the authors for use as a laboratory exercise to teach basic circuit elements and circuit analysis. Although Gamification in education is not a new concept [5-7], what we are presenting here is a new application of gamification in the college engineering classroom setting. In reference [5] games are shown to increase interest and retention of concepts, but much of the work is focused on the middle to high school grade level. In [6] gamification using apps and technology are the focus, and they are shown to improve retention and engagement. Lastly [7] focuses on a discussion of how to use various game elements to enhance specific lessons and achieve significant success. Here, we present a type of gamification, previously explored by the authors [3], wherein the focus is to create full games that are explicitly designed to teach a particular topic in physics education.

Game of Ohms was played by second semester physics students in a two hour laboratory setting. Students were typically second semester freshman or sophomores mostly in engineering majors, but also including students in computer science or applied math programs. The engineering programs at Wentworth Institute of Technology strongly focus on project-based learning. Devices and prototyping are therefore an integral part of many of the courses for which physics is a prerequisite. Hence, it is essential that students leave with a working knowledge of basic circuit concepts as well as an appreciation for the complexity that can arise in circuit analysis. Given this population, the main learning outcomes of the new game-based exercise were for students to:

1. Demonstrate the ability to add resistors in series.
2. Demonstrate an ability to add resistors in parallel.
3. Decompose a complex circuit into its basic elements.
4. Work together as a team to accomplish a goal.
5. Demonstrate the ability to adapt to rapid changes in a circuit design.

It should also be noted that a further goal of this exercise was to overlap with other concepts encountered early in the second semester of a physics sequence, such as estimation and flow of charge through a wire, voltage properties, and Kirchoff’s laws.

Below we provide a brief overview of the resistor game lab setup, assessment of students, data collected from our first implementation of the lab, and future work to be done on the game. We will also discuss intangible data such as student engagement and participation. It is our hope that other instructors will see the potential in such a learning tool and provide feedback to improve the student experience.

Experimental Overview

In the design of a game to be used in a laboratory exercise, there are two main issues to consider. First, the game has to be one that can be learned rapidly, so that students can spend their time playing and learning rather than scrutinizing rules. Second, the game must preserve, and ideally enhance, the lesson to be taught. In Game of Ohms, two teams compete to make a circuit that has a particular resistance. Each team is assigned a goal value in secret. The teams alternate adding to the circuit to achieve their goal. In the process they build a complex circuit. Finally, the two teams must work together to find the final resistance of the often convoluted circuit they created.

Experimental Procedures

The full rules for Game of Ohms can be found in supplementary material [4], but in this section we give a brief overview. Game of Ohms is played on an 8x8 grid board similar to a chess board. There are several decks of cards for the game. The Primary Objective and Secondary Objective decks are used by students to determine their win conditions before the start of the game. The Resistor Deck is used to supply the players with their hand of five resistor cards. Players draw from this deck to replenish any resistors they have expended during play. The Wire Deck is used to form a Texas Hold 'Em style pool of wire cards that have zero resistance from which either team can play cards.

The week leading up to this lab, resistors and basic circuit theory were covered in the lecture portion of the course. Students were given the rules of the game ahead of the lab, and were expected to familiarize themselves with how Game of Ohms works. After a brief introduction, teams of three or four players were formed, and these teams were paired against each other by random draw. Each team drew a Primary Objective card which established the total resistance their circuit should reflect by the end of the game. The teams also drew three Secondary Objective cards, of which they then chose two to keep. Secondary Objective cards specified particular features about the circuit, such as number of resistors in a particular series set, or number of parallel wires in the circuit. Play then commenced, with the winner of a single round of rock-paper-scissors making a move first.

Each turn, a team placed either a resistor card from their hand or a wire card from the common pool, connecting it to the circuit in play. As the circuit evolved, each team had to continuously update their calculation to determine how close the circuit was to their desired resistance. The game is highly fluid, as any given move may dramatically change the resistance of the circuit by introducing parallel branches or even causing shorts which eliminate paths. The Resistor Deck also included 'Solder' cards, which could be used to remove a card already on the board and replace it with another, increasing options for strategic play and adding to the amount of overall calculations required by each team.

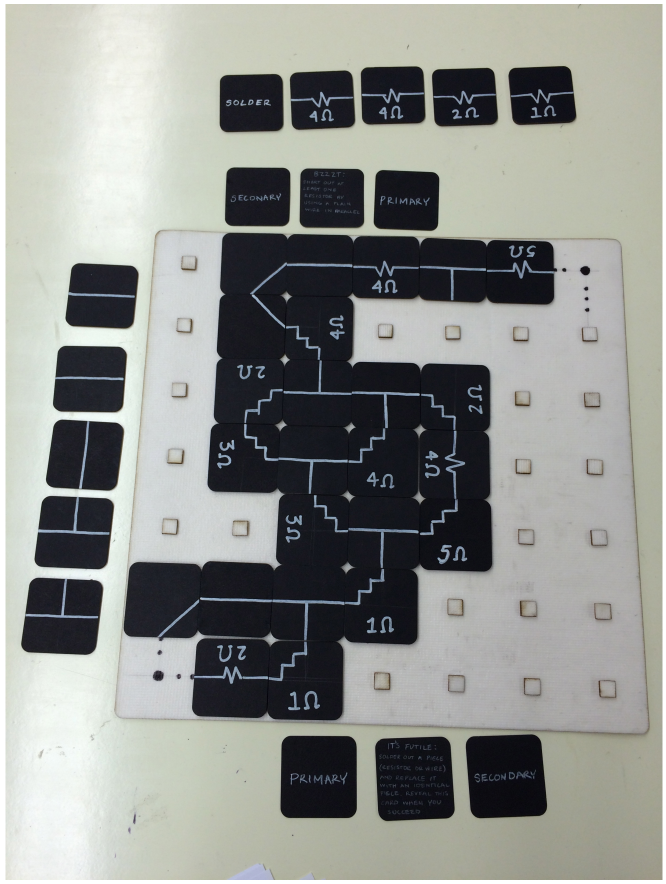

Figure 1: A game in progress. Tiles are played to the board to build a circuit. Each element is either a resistor with the labeled value or a wire (as seen on the left) with no resistance. In this image, the circuit has been completed, and the students were in the process of evaluating the total resistance.

When the game concluded, the two teams had the task of working out and agreeing on the final resistance of the circuit. Challenges included identifying and reducing parallel components as well as dealing with open circuit elements that had not been closed. Assuming the two teams could come to an agreement on the final resistance, they could then score the game. The team that got closest to their Primary Objective received 2 points. Each completed Secondary Objective was worth 1 point.

Grading of the exercise was performed based on the scored points. In this way, teams were motivated to play competitively and achieve any and all objectives. In a three game lab session this meant students could earn up to 12 points, which earned them an A for the lab. Once comfortable with the rules, many students were able to play more than three games in the time allotted, and we encouraged students to stay and play as long as they liked in order to bolster their overall score on the lab exercise.

General Discussion

The game was designed so that students were very quickly forced into engaging with the mathematics of circuit calculation. In order to have a handle on their goals, teams had to keep track of the expected resistance of the circuit as each move was made. Usually by turn three, groups were immersed in heavy calculations to predict likely future moves. The teamwork fostered by the competitive atmosphere encouraged peer-learning so that everyone could contribute. Before the conclusion of the first game, most students were able to grasp the overall lesson and contribute to the advancement of the team's objectives.

Although in general the students had a grasp of the topic from lecture, as in any new assignment, students are often initially hesitant. Groups would at first labor over the initial placement of cards. As the game evolved, they were able to make quicker and more informed decisions. Often they had to reconcile their initial moves with the changing board, making decisions later in the game to create new parallel or series combinations and offset earlier errors. In lecture, students often wonder why certain combinations of resistors might be chosen in a real situation. Part of the lesson in this exercise is the discovery of how resistances may need to be manipulated in a real circuit to achieve a desired effect. Some games took slightly longer than others, but on the average, students finished their first game in about thirty minutes. After the first, few games lasted more than twenty minutes, since students could adjust in a quicker fashion to the evolution of the circuit and had a better understanding of the rule set. Students found the competition an exciting change of pace, creating a very engaging atmosphere. Even with a lab grade at stake, successful teams would vie for the opportunity to face other winners and increase the challenge in their learning process.

Ideally, laboratory exercises should be viewed positively by the students, and embraced as a way to have a hands-on experience with the material from class. After the first implementation of this game exercise, we feel as though the intangible measure of engagement was exactly what we had hoped. There are typically few moments in the basic electricity and magnetism labs where students are engaged in the material as well as actively involved in with their peers. This may be due to the constraints of the standard experiments in the curriculum or the cumbersome equipment involved that can obscure the connection between theory and practice. In the game environment, however, the feeling of "fun" helped even struggling students approach the game as a learning experience. The competitive atmosphere placed a personal responsibility on each team member to contribute, which we believe helped internalize the lesson [4]. Students were polled using a simple online survey and an overwhelming majority of participants believed it to be fun as well as beneficial. Students who were not exposed to the game lab expressed their discontent to the instructor on learning of its existence and implementation in other sections.

Data on Learning Outcomes

In order to try and measure the effectiveness of this lab at meeting the desired learning outcomes, data was collected across a sample of about 150 students using various methods. The first method was to split the participants into two groups of 75. Both groups performed the traditional exercise of connecting resistors in series and parallel, but one group would also play Game of Ohms while the other group would not. The groups were also exposed to a pre and post-lab exercise which contained three components (for the complete pre-post exercise please see [4]): A simple series and parallel circuit, an advanced circuit consisting of a complicated branch of series and parallel resistors, and an inquiry problem asking students to construct a circuit of their own design of a specific resistance using only resistors from a known pool. The results of these assessments were directly correlated to what we hoped to achieve with the game. Although both groups performed similarly on the simple circuit section, significant improvement in understanding the more advanced circuit was shown by those who played the game. Game participants had an average score 11% higher than students who did not play. The most convincing piece of evidence was the overwhelming improvement on the inquiry circuit. Students who did not play the game showed little to no improvement on their pre and post scores, while the students who played the game in lab were able to solve the inquiry problem with much greater expertise. This result confirms that the logic and creativity learned in the game improved content retention and problem solving ability. It is our belief that the objectives of the exercise were met with a resounding success.

Equally important is the accessibility of the material to the student. To this end, we monitored the overall time spent on the lab exercise versus the similar exercises performed in the control group lab. Typically in groups of four, 1-2 students would take the helm and finish the assignment while others documented the progress. Engagement was low and there was a rush to complete the lab, which students averaged in thirty-five to forty minutes. For Game of Ohms, groups were required to play a minimum of three games. Once students master the simple rule set, games only take about twenty minutes, yet on average students stayed for 118 minutes, just two minutes shy of the overall two hour lab period. Most groups played four total games when only required to play three. The competitive atmosphere grew as students continued playing, increasing the interaction between groups. At one point, students even spontaneously organized a round robin tournament.

One issue in any group activity is the level of individual involvement. In a traditional lab, more competent students typically dominate group work, while lagging student fail to engage. Often, both student types are satisfied with this arrangement and little to no transfer of knowledge occurs between the two. The design of Game of Ohms, however, invites all participants to offer strategies. While pursuit of the primary goal involves calculations more suited to the mathematically prepared student, secondary goals are more aesthetic in nature. Thus, students still struggling with resistor addition can contribute, and the competitive environment of the game encourages them to do so. Moreover, students must debate the advantages of suggested options. In doing so, more advanced students explain concepts and lagging students are self-motivated to improve. Relatively quickly, new and more creative strategies are offered by all students, with rigorous discussion and planning as a team. The overall learning environment of creativity and teamwork is indicative of far greater interaction between students than that seen in the traditional setting.

Overall, the energy and engagement in the room was quite high, and itself fostered a supportive learning environment. Students could be seen walking around the table, analyzing the circuit, discussing their potential next move, analyzing possibilities of their opponents move, performing calculations and actively engaged in a competitive environment. Frequent eruptions of cheering and dissent could be heard as the games become more complex and intense. All of these interactions helped contribute to the overall positive and competitive atmosphere of the room. Students wanted their clever moves and last minute efforts to be appreciated by both the faculty and other students. It is this type of environment that we believe the students will recall fondly long after the course, and hopefully lead to greater retention of the material that is associated with those memories.

Perhaps one of the most positive outcomes of the experience is that the game forces students to analyze complex circuits in order to establish the winner of the game. The intricate circuits generated by gameplay are a much better analog for real world circuits than the rather simple examples students are generally exposed to in textbook exercises. It should also be noted that although the convoluted circuits the students generated called for more difficult calculations, the students were less intimidated such due to their personal investment in the design.

Based on these observations, we believe the learning outcomes were achieved with high success. The main goal of Game of Ohms was to create an engaging atmosphere for students outside of traditional learning techniques. As Game of Ohms is now in its second phase of development, we hope to provide more statistical analysis by the time this draft becomes a finished version.

Design Work Collaboration

It is our intention to give this game a full design treatment, taking it from the somewhat rough but serviceable form we developed initially to one that has been polished by designers expert in making a solid functioning product. As part of this development process, we also hope to include new modes of game play. We would like to expand the repertoire of the game to circuit theory problems beyond just series and parallel resistors. Game modes could include capacitors, power sources, additional nodes and other advanced concepts. This task is undertaken primarily by one of the authors' senior design class in the Industrial Design department.

From a design standpoint this project acts as an incredible platform. It exposes students to a number of real world design challenges from working across multiple design disciplines to collaborating with different stakeholders all the while doing it in a team setting. With the success of last years' "Sector Vector" development the course in which development of Game of Ohms will happen has been further refined to allow students to focus on delivering the highest caliber experience for their peers who will ultimately be playing the game.

As designers the focus is always on creating the best experience for all parties involved. This means creating a product that will provide the students with an engaging and fun game but also provide educators with a new tool to help reinforce the learning objectives. All of this begins with research, experiential and observational. The design students spend time learning how games are designed by playing and analyzing a wide variety of games and sharing their findings. This includes the prototype for the game they'll be working on for the semester. Industry professionals also lend their expertise with on-campus visits to provide students with insight into how games are brought to life and why some are more successful than others. All of this is to provide a valuable baseline for when the actual gameplay is observed.

It is at this stage that designers observe science students playing the game. It goes far beyond simple observation. The experience is documented in writing and through video and photography for later analysis. Student players are interviewed about their experiences and interactions with the game, each other and their professors. It's from this research that the designers will find opportunities to enhance gameplay through the development of tangible and intangible components.

In the weeks following, the design students work to ideate and develop radically different prototypes – permutations that will be tested, refined and iterated on until a final solution is reached. These prototypes begin as drawings and written explorations that quickly turn into physical, playable constructs. At each turn the students will be conceptualizing how all of the components of the game will work together from the graphic identity of the game to the game board and pieces to the rules and gameplay itself.

Conclusion

Our initial success in gamification led us to this work, in which we developed a way to teach a complex topic to students in a highly engaging vehicle. Modern pedagogy has been shifting towards more student engagement, more hands on learning, and more interactive delivery methods. Game of Ohms makes use of all of these concepts, with exceptional student response, and notable improvements in concept retention. We plan to expand this delivery vehicle to more topics in circuit theory, making it possible to use Game of Ohms for a whole sequence of learning experiences in the physics lab.

References

[1] 'Game of Ohms' while an excellent name in and of itself, is our current placeholder, which we expect to be revamped as part of the design process taking place this semester.

[2] David R. Sokoloff, Ronald K. Thornton and Priscilla W. Laws, "RealTime Physics: Active Learning Labs Transforming the Introductory Laboratory," *Eur. J. of Phys.*, **28** (2007), S83-S94

[3] James G. O'Brien and Greg Sirokman, "Teaching Vectors to Engineering Students through an Interactive Vector Based Game", *American Society of Engineering Educators Conference Proceedings, 2014*

[4] Supporting documents for this paper can be found at: myweb.wit.edu/sirokmang/resistance.html

[5] M. Wagner (2013) ON THE GAMIFICATION OF EDUCATION, *INTED2013 Proceedings*, pp. 2027-2034.

[6] LEBA, MONICA, ANDREEA IONICĂ, and DRAGOȘ APOSTU. "Educational Software based on Gamification Techniques for Medical Students." *wseas. us* (2013): 225-230.

[7] Kapp, Karl M. *The gamification of learning and instruction: game-based methods and strategies for training and education*. John Wiley & Sons, 2012.