Gamification of Electric Circuits Education

A graduation project report submission
In partial fulfillment of the requirements for the award of the degree
Bachelor of Science

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June 2023

2022-2023

Abstract

In the current academic and research scene, the topics of embedded systems and robotics are of high interest and need, though learners often find that they lack the needed fundamentals in electronics to conduct their projects and research. This project proposes a visual education solution for fundamental electronics and electric circuit simulation, by harvesting the concepts and technologies of gamification, game design, and puzzle design.

Recent literature, projects, and gamification attempts are reviewed, and it is found that gamification of education yields many positive results due to (a) increased engagement, and (b) learners' eagerness to collect achievements (trophies), along with several other factors. The game production industry is home to countless professional talents in engineering, art, design, and management; our project, a 2D puzzle video game, is an attempt at combining said talent with the thoroughness of academic curriculums, to bring together an entertaining, yet fruitful educational experience.

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Chapter 1

Introduction

1.1 Overview

Electric circuits are really important. In a world filled with electronic devices and appliances, circuits are everywhere, from the smartphones we carry in our pockets everyday, to the cars we use to move around, or the complex power grid systems we rely on. Although all of the things previously mentioned vary greatly in a lot of ways, they all share the same basic electrical concepts and components.

1.1.1 What are electric circuits?

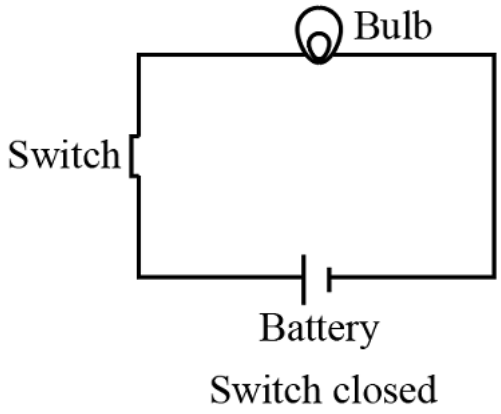


Figure 1.1: Basic electric circuit

An electric circuit can be described as a closed path or a loop that acts as a continuous pathway for electrons to flow, this flow is what we call electric current. Circuits can be represented in many different ways. Essentially, all you need to have a circuit is a conductive material and a power source, you can then use the current of electrons flowing through the circuit to power any devices you want. A very simple example of a circuit is one which contains a battery, a wire and a light bulb, figure 1.1 demonstrates how such a circuit would look like. Circuits are usually made up of several basic components, each component can be categorized as either:

1. An active component: which is An electric circuit element which can supply electric power to the circuit or power gain in the circuit. Examples of such components are:
    - Batteries.
    - Amplifiers.
    - Transistor
2. A passive component: a circuit element which can only absorb electrical energy and dissipates it in the form of heat or stores in either magnetic field or electric field. Examples include:
    - Resistors.
    - Capacitors.
    - Inductors.

Each of these components can also be of different types each of which are more suited for different functions, for example transistors can be bipolar, junction, field-effect.

1.1.2 Electric circuits' impact on our lives

Electric circuits form the fundamentals of modern day societies, they allow us to harness and control electricity and use it to make our lives easier. Many aspects of our day-to-day lives depend on them. To really feel the impact of circuits on our lives, try to think about any electric device or appliance, without circuits these things would cease to exist, take for example the artificial lights that light up our nights, a thing we take for granted and completely depend on. Another example is computers. Computers are involved in almost everything in our lives, either directly by being a part of the device itself, or indirectly by being involved in the manufacturing process.

1.1.3 Electric circuits educational challenge

1.1.3.1 Electric circuits education

Thus far we have established the importance of electric circuits in our lives, and that should lead us to the following conclusion: in order to maintain the technological innovations and developments, we need a lot of people to have a professional understanding of how circuits work, how they are designed and built, and how they can be utilized properly. Luckily a lot of people have come to that conclusion many decades ago, and now students in schools and in Science, technology, engineering, and mathematics (STEM) related university programs do study electric circuits to some extent.

1.1.3.2 The challenge

Students often find the topic of electric circuits to be a daunting or a complex topic to study, it is a topic often associated with the idea of being difficult. And that applies to both the theoretical side and the practical side of the learning process, it is a demanding topic that requires the student to have an understanding in multiple fields such as mathematics and physics. And even solutions such as circuits simulation programs most of them are old, not so user friendly, and require a level of proficiency with the program itself before a student can start using it. Latest studies suggest that students often find problems understanding topics such as current and voltage behavior in sequential and parallel circuits (Bowman et al., 2007)[**1**].

1.1.3.3 Our proposed solution

Our proposed solution to help circuit students of all levels is to make an educational game, the game would offer them an interactive gamified learning experience with a decent learning curriculum. The main goal is to guide students along a journey of building different circuits with different purposes, and along this journey the student will be learning about different components and different characteristics they possess, and how components connected together in a certain way could make a useful circuit. A reason for why people like playing games and spend so much time doing it is that games are fun, entertaining and rewarding. And that will be a core focus for our game. A big part of the gamified learning experience is keeping students interested, and eager to continue completing more levels of the game, and that can be achieved by adhering to game design techniques, and having an educative yet enjoyable directory of available levels.

1.2 Gamification and education

1.2.1 Gamification

There have been a lot of different definitions for gamification with different perspectives from different authors. Dixon, Khaled, and Nacke suggested defining "gamification" as "the use of game design elements in non-game contexts". van Grove(2011) [**2**] "Gamification is to change something that is not a game through a game or its elements.". MacMillan (2011) [**3**] " Gamification, defined as the use of game mechanics, dynamics, and frameworks to promote desired behaviors". So we could simply say that gamification is the systematic process of applying game mechanics to non-game contexts to make difficult tasks more enjoyable.

1.2.2 Gamification as an approach

Gamification is not just a technology, it is a psychology. Of the many fields within psychology, behavior analysis has devoted itself to precision in the understanding of, and perhaps more importantly the control of human behavior. A consideration of the principles generated by behavioral psychologists might be useful in explaining how specific game design elements motivate and maintain user engagement, and knowledge of the principles and processes defined by behavioral psychologists can readily help in the design of more useful and engaging gamified experiences. To design a successful and enjoyable gamification, a deeper understanding not only of games and play but also of the processes through which it is possible to incentivize people to behave in an appropriate or a productive manner is needed. Gamification offers a way for engaging and interactive education; plus, gamification actually aids in memory. According to Foerde and Shohamy [**4**], during gamification learning, a strong hippocampal[1] activation makes the content easier to remember and recall.

1.2.3 Gamification purposes

Purposes of gamification differ from one to another, as a sense of purpose is integral to the field and circumstances it is used in. Also the human experiences should be taken into account. We believe that the main purpose of gamification is helping people to move from one point to another in their lives whether it is used for personal growth, societal improvement or marketing engagement. Also one of the main purposes of gamification that should exist in each gamification process is inspiring the users, giving them the motivation and encouraging them gracefully, effortlessly leading them into a steady stream of knowledge and experience, as successful gamification will tap into the user's intrinsic motivation[2].

1.2.4 Real impact of gamification

According to a gamification survey made by TalentLMS which focused on productivity, motivation, and gamification for employee engagement. 83% of those who receive gamified training feel motivated, while 61% of those who receive non-gamified training feel bored and unproductive. 89% believe they'd be more productive if their work was more gamified. [**5**]

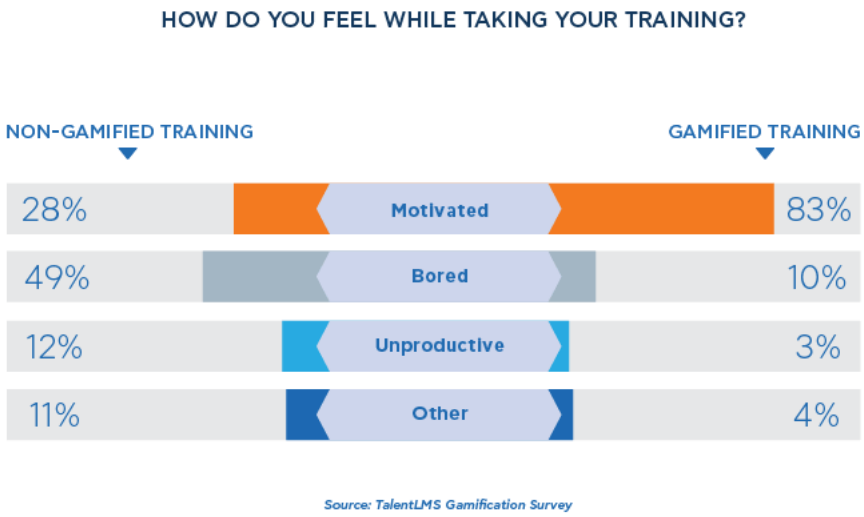
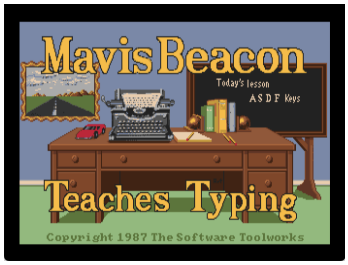


Figure 1.2: TalentLMS Gamification Survey

[1] Hippocampus is a complex brain structure embedded deep into the temporal lobe. It has a major role in learning and memory.

[2] Anything at all that makes you feel good within yourself is fueled by intrinsic motivation.

(a) Number Munchers (1986)



(b) Mavis Beacon Teaches (1987)

(c) MasterType (1981)

Figure 1.3: Old educational games

1.2.5 A brief history on gamification

The gamification field as we know it started in late 2010, and it took its roots in the idea of using game elements and game designs in non-game contexts to reach various goals while increasing user engagement and motivation. Although the term has only been around for about a decade. History has witnessed numerous different things that have come together to form the rising industry of gamification. In 1896, Sperry & Hutchinson (S&H) made a meaningful step in the use of gamification; the company launched a stamp business. The number of S&H stamps that customers collected from grocery stores, gas stations, and other businesses varied depending on how much money those customers spent on their products. The clients could then trade in their stamp collections for goods like various housewares. For educational purposes, games such as The Oregon Trail and Lemonade Stand were produced in the 1970s. In the 1980s, more efforts to use gamification for education were made. Gamification has an exciting future. This field has the potential to save industries millions by simulating training in an immersive and realistic environment that increases motivation and engagement. Gamification can generate learning and growth results that are better to those from any other strategy we have used in the past if it is implemented properly. It's time to take advantage of modern technology and our understanding of how the brain functions to improve performance and outcomes in a variety of contexts. A significant step in the right direction is being achieved through gamification [**6**], [**7**].

1.2.6 Educational gamification

Many educators face problems related to engagement and concentration of their students in their classrooms. These problems are not something new through generations, educators tried solving these problems using motivational and learning strategies, however its effect did not last long as something in this environment fails to engage the students. The fun and playful nature of the game can be a good solution. Educational gamification proposes the use of game-like rule systems, player experiences and cultural roles to shape learners' behavior, as it is an approach that seeks to motivate students and inspire them to learn, understand and concentrate easily. Understanding the role of educational gamification, means understanding the circumstances of the game elements that can drive learning behavior.

1.2.7 Motivation and engagement

Motivation and engagement are concepts that are often used within the context of gamification. The properties of motivation and engagement are very complex as there are so many intertwined factors that can influence them. The quality of motivation and engagement needs to be understood. The motivation has two components (energy and direction), and engagement can be understood as the directional expression of motivation: when we direct our energy toward something or someone, engagement is observed. Engagement is not synonymous with motivation but is the behavioral expression of a motivated state. Self-determination theory (Deci and Ryan 1985, 2000) [**8**] suggests that the key to building successful gamification applications largely rests in:

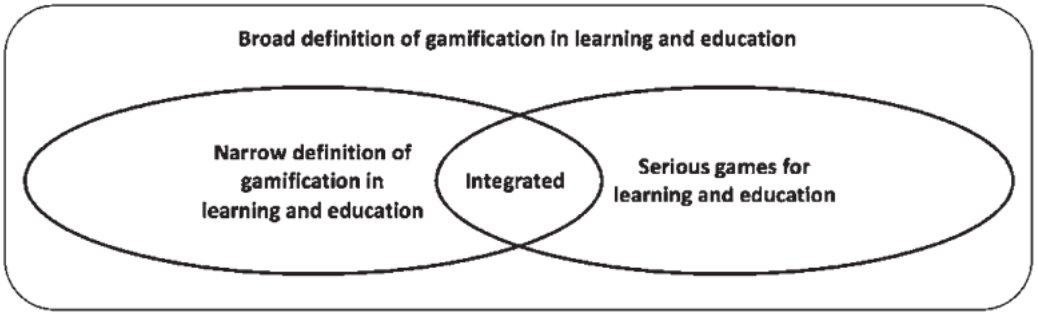


Figure 1.4: Broad definition of gamification in learning and education

1. Understanding the energy that fuels our behavior.
2. The various forms such energy can take.
3. The ways in which we can apply this knowledge in the development of strategies, designs, and techniques to optimize the quality of motivational energy to achieve gamification's goals.

Which allows students to engage more in education through playing a game and having competition between themselves [**9**].

1.2.8 The effect of gamification on students

According to the International Journal of Education and Learning Systems [**10**], during the winter semester of the academic year 2016–2017, a study was carried out in which 20% of ZSEM[3] undergraduate students took part. Eighty percent of the students who responded to the survey stated they were using gamification in at least one class. Students rated their happiness with the use of gamification in their courses on a scale ranging from 1 to 5. Of those, 67% gave it a 5, 26,8% gave it a 4, barely 5,2% gave it a 3, and only one student expressed dissatisfaction[4]. 90% of students gave gamification a rating of 4 or 5 when asked how much it motivated them to attend lectures. Also, 86% of students said that gamification improved their grades. Additionally, the majority of students concur that gamification needs to be included in the majority of the courses. Students showed their support for gamification in class in open responses because it helps them review their lectures through entertaining games and gives them more motivation.

[3]Zagreb School of Economics and Management
[4]Student satisfaction in using gamification in class

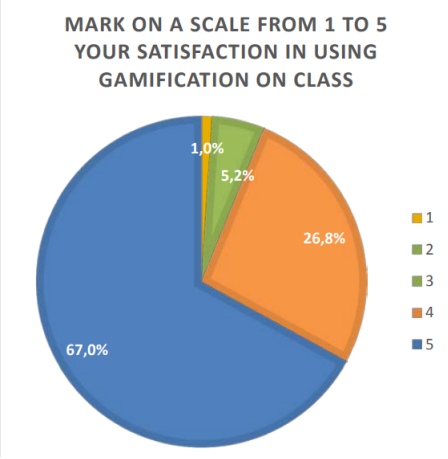


Figure 1.5: Students mark their satisfaction from 1 to 5 using gamification in class

1.3 Game development

1.3.1 What is game production (development)?

Game production, or as it's more commonly referred to, game development[5], is the process of creating a video game (or any kind of game for that matter). It involves a tight combination of art and science, involving artistic creation skills, design, programming, engineering, testing, and possibly many more depending on the type of the game being developed. Long before its commercialization and the game industry becoming a $200 billion industry, game development began around the 1950s on mainframe computers, until the first generations of commercial game consoles and arcade games became popular around the end of the 20th century. Nowadays, there are countless game studios ranging from a single developer to an international team dispersed across the globe, creating massively distributed multiplayer games, or singleplayer AAA titles comparable in production size and budget to Hollywood blockbusters. What exactly happens behind the scenes though? Why do games need that large of a team and wide skill-set?

1.3.2 What is game design?

Game design is a major sub-process of game development. It is concerned with defining the rules of games. What restrictions are there? What can the player do? How can they do it? What can't they do? What's their goal? How do they win? How do they lose? Is the game too easy? Too hard? Is this weapon too powerful? Is the game too simple? Too complex? What assumptions about the player's background does the game make? What experiences is it trying to convey? Does the game have a purpose besides entertainment? Game designers aim to define, prototype, communicate, and document the answers to all these questions and many more.

Normal (classic) game design vs video game design

Classic games were technologically restricted, that is, there was a lot that they couldn't do. They had to compensate for the lack of technology through game theory and game design, restriction forces creativity. A lot of the concepts used today in game design are borrowed from classic games.

[5] 'Game development' is also often used to refer to all implementation-related tasks, like programming, algorithm design, etc... For the rest of this document, 'game development' will be used to refer to the whole production unless otherwise is specified.

1.3.3 Why is game design important for gamification?

Gamification aims to make an otherwise dull experience tolerable, if not desirable. Good game design must be practiced, otherwise either the essence of the topic will be lost (preserve the essence of the topic), or the experience will just be dull, or even leaving a negative impression on the topic.

1.3.4 The game development team roles (and other stakeholders)

A lot goes into bringing a game to life, making game development and production a process that can take years, sometimes with teams into the hundreds depending on scope and budget. Here is a list of some of the core roles involved in game development [**12**], [**13**].

1.3.4.1 Game designers

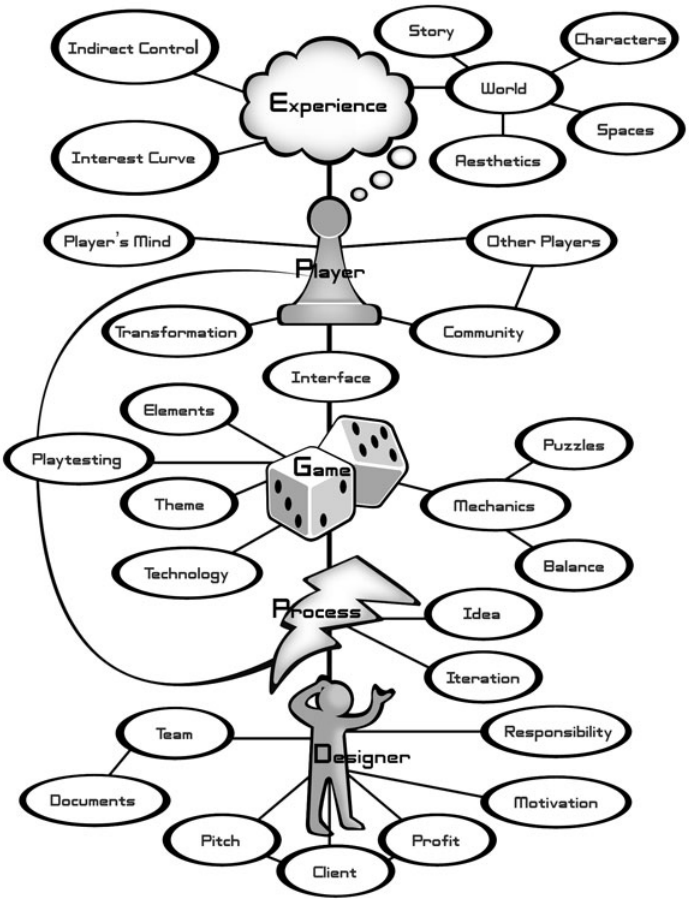


Figure 1.6: Schell, J. The Art of Game Design: A Book of Lenses, Second Edition: Chapter 34 (Complete game design map)

Game designers handle creative elements of the game. This can include (but isn't limited to) storyline creation, character definitions, game rules, goals and challenges. Anyone involved in the game's development and responsible for making decisions, be it small or big, can also be considered a game designer. Game design requires both creative and technical competence; game designers may need to be artistic, possess creative and technical writing skills, as well as basic programming/scripting skills. In "The art of Game Design" by Jesse Schell, he suggests that any skill that you have can be (and will be) relevant to game design. These skills can be: animation, anthropology, architecture, brainstorming, business, cinematography, communication, creative writing, economics, engineering, games, history, management, mathematics, music, psychology, public

speaking, sound design, technical writing, visual arts, and many more [**14**].

Key game designer roles

- Lead designer
- Content designer
- Game mechanics designer
- Game rules designer
- Level designer (often a dedicated role due to importance and high workload)
- Environment designer
- System designer
- Game writer (story-line, characters, back-stories, lore, dialogue, etc. . .)

1.3.4.2 Game programmers and engineers

1.3.4.3 Game artists

Game development is an artistic production as much as it is a technical production. This group is responsible for bringing life to the game through colors,Visual effects (VFX), animated 3D models, musical compositions, and much more. Game artists specializations are vast: character design, architecture and landscapes, lighting, modeling, special effects, texturing, and animation.

Key game artist roles

- Character artists
- Concept artist
- Environment artists
- Asset artist
- Technical artist
- 3D model artist
- Animator
- Sound effects (SFX) artist
- Composer

1.3.4.4 Some other stakeholders

Larger scale games are not limited to the roles mentioned, and each game may outsource or dedicate internal talent to other unexpected fields as per need. Some more stakeholders in the game development industry may be (but not limited to):

- Quality assurance (QA) testers
- Project managers
- Game publishers & distributors
- Creative directors
- Domain-specific/research consultants
- Localization teams

1.3.5 Puzzle Design

1.3.5.1 Common definitions of a puzzle, and historic context

A puzzle, in general, is a problem, game, or toy that tests a person's problem solving skills in a given field or topic. A puzzle game is a game that focuses on challenging the player through logical thinking, as opposed to action or adventure [**15**].

1.3.5.2 What is puzzle design?

In order for a puzzle game to be successful, it needs to balance between difficulty, and reward. However, puzzle design is not just a matter of putting together a sequence of levels of increasing complexity; most puzzle games rely on logic in addition to another skill that the game either teaches the player or assumes they understand (in our case, electric circuit design).

1.3.5.3 How puzzle games are different from normal games (and what makes puzzle designers special)

Puzzle game design differs from normal game design for multiple reasons; for one, the target audience is different, and for another, it's much easier to design a frustrating experience when the action elements of video games are taken out. Puzzle designers might need to possess special skills, such as exceptional logical thinking or game theory knowledge for puzzles combinatorial in nature. In our case, out puzzles are circuit-based, and will require (from the designer's perspective) a good handle on electric circuits, alongside standard successful puzzle game elements such as [**16**]:

- The game has a central mechanic that is easy to understand, but hard to master.
- The game should provide the player with all the information they need to complete the level, and understand the concept it's teaching.
- Allow for the player to experiment, and get feedback on wrong solutions.
- Maintain balance between difficulty so that the player stays engaged, while making sure not to frustrate the player.

1.3.5.4 Relation between education, learning, puzzles, and circuits

Putting together a circuit to satisfy a specific function is a puzzle; given a 5V battery, 3 100Ω resistors, and a standard red LED, how do you put together a circuit such that the LED is at highest brightness? How about the lowest brightness? What configurations could burn the LED out? These kinds of questions are puzzles in their nature, and the metaphor easily extends to other fields of education as well, not just electric circuits. Education as a learning approach, can be extended with engaging gamified experiences through puzzle games, that aid understanding, and facilitate an accessible way of experimentation, at lower costs and no risks.

1.4 Problem definition

1.4.1 Challenges encountered by students when learning about electric circuits

Most students regardless of their scientific level often find the idea of learning about circuits a very intimidating one, it is a topic that has been discussed and researched many times. Students from all levels may find difficulties in understanding topics such as voltage, current, and how these properties are affected by different components in a circuit. This can be seen for example in the research administered by Carol Bowman and Gordon J. Aubrecht, II [**1**], they found that students find the concept of voltage very confusing, and that is due to the fact that students first start by learning about current, then when they start learning about voltage they apply the idea of flow which applies to current, as a result students start confusing the two concepts together, and that

it is despite careful texts which attempt to clarify the difference among the two. Another challenge that students face nowadays is their very short attention spans. Students need something engaging and entertaining to keep them interested, traditional methods such as long lectures, and large textbooks, while informative, but they lack the attention grabbing element, students get bored and lose interest. According to Neil A. Bradbury [**17**] several institutions have brought down the length of lectures to only 15 minutes. This is based on the belief that a lecture any longer than 15 minutes is not going to be effective for students. Traditional techniques of circuit analysis do not provide students with the required skills for dealing with electric circuits effectively, students need to develop an intuition when analyzing circuits (Fino, 2018) [**18**].

1.4.2 The materials available are geared towards professionals

Many of the materials available to students are complex and require mastery of prerequisite skills such as mathematics and physics, surely there is an argument to be made for such materials, as they actually can be helpful for professionals as well as provide readers with a deeper understanding and intuition about the subject. But they aren't particularly very helpful for beginner students trying to make their way through. As a matter of fact they can be confusing and discouraging, as they require the students to dedicate a long period of time to understanding how to effectively make use of the information presented, thus creating a barrier of entry. According to the authors of Should Textbooks Challenge Students? [**19**], not all students can learn at the same pace, therefore textbooks should provide an average challenge that can suit all students. According to (D. Sangam and B. K. Jesiek, 2015) [**20**], textbooks on electric circuits often lack important conceptual features, and that can pose a problem for beginners approaching the subject.

1.4.3 Physical laboratories aren't enough

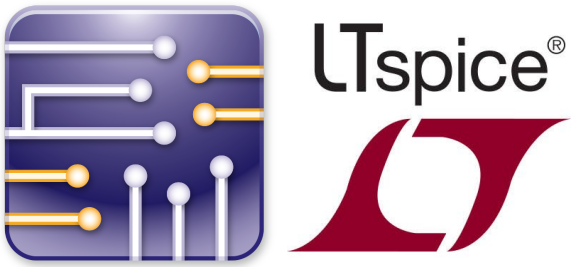
Available electric circuits courses usually rely only on textual materials to explain the subject, and while this kind of material is unquestionably important, it is not enough. Since electric circuits require practical and hands-on experience, some courses incorporate some form of hands-on practice through laboratories, according to Bayrak, Kanli, and İngeç [**21**], students learn information best when they can see the concepts and processes at work in the real world, but it's not often that students can be surrounded by the real thing as it can be dangerous or inconvenient, that's why stimulated environments such as laboratories are utilized. Although laboratories have their benefits, but they also come with limitations such as:

- Components and tools being expensive to provide for every single student.
- Difficulty in managing a large number of students in the classroom.
- It takes too much time for teachers to plan such activities.

One method for overcoming those limitations would be to rely more on digital means for providing students with those stimulated environments, such as computer simulation programs. Simulation programs offer a variety of electrical components available for the student to use them in a circuit. There are also a lot of free and open source versions of such programs.

1.4.4 Simulation programs aren't beginner friendly

According to Jaakkola, Nurmi, and Veermans [**22**], students can gain better understanding about electric concepts when they combine both the real hands-on circuit experience, and also the use of computer circuit simulation programs. And that is great but usually circuit simulation programs aren't beginner friendly and they require the understanding of their own notation, for example SPICE based simulators support their own unique commands. In addition to this most GUI-based SPICE simulators are outdated and hard to work with, not to mention the lack of convenient clear documentation or tutorials on how to make proper use of the software. According to (Alasdoon, A. & P.W.C, Prasad & Beg, Azam & Chan, A.., 2013) [**23**], commercial circuit simulators are great for use by professionals. But when it comes to students these programs have many disadvantages



(a) NI Multisim **(b)** LTspice

Figure 1.7: Popular circuit simulation software programs

mainly because they are designed for commercial purposes and for the professional market. For example they might not have the basic simple functionalities that students require to finish their tasks, which might result in students getting confused.

Chapter 2

Related work

2.1 Recent relevant literature review

2.1.1 Electric circuit education literature review

This section provides a review of the literature relating to electric circuit education, how it is and how it can be improved.

2.1.1.1 A Case Study for Comparing the Effectiveness of a Computer Simulation and a Hands-On Activity on Learning Electric Circuits. (Ekmekci, A., and Gulacar, O., 2015)

Methodology:

1. Researchers would gather the students' answer to the test a week prior to the day on which the study was to be conducted.
2. On the day of the study, students would be divided into two groups, the students in the first group would be given a collection of circuit components, while the other group were told to use a circuit simulation program installed on their computers.
3. Both groups were then given a lesson about circuits to further enhance their knowledge about the subject.
4. After the lesson, students were tested once again, to measure the impact of their understanding and compare the differences between effectiveness of both hands-on and simulation learning experiences.

The results

Table 2.1: table showing the results of a test before a study (Maximum possible score: 8)

	n	Mean	S.D	Lower	Upper
Computer-based	16	4.38	1.45	3.69	5.08
Hands-on	20	5.20	1.44	4.44	5.80

Table 2.2: table showing the results of a test at the end of a study (Maximum possible score: 8)

	n	Mean	S.D	Lower	Upper
Computer-based	16	5.31	1.35	4.69	5.94
Hands-on	20	5.95	1.28	5.32	6.43

We can see from the results above that all students received a similar improvement to their test scores. Thus it is concluded that incorporating any form of interactive learning can be beneficial and will increase the quality of the students' learning experience, regardless of whether it is a hands-on experience or a computer simulated one.

Conclusion

Even though all students gained a significant increase in their understanding of electric circuits after being exposed to both hands-on and computer simulated experiences, the researchers noticed different results when considering areas other than their test scores. They found the following:

- Students in the hands-on group had gained an increase in the level of their engagement and interaction compared to the computer simulation group, but the researchers think that this is could be simply due to the fact that in the computer simulation group each student had their own computer, and if they had just one computer mabe their engagement would have been as high as the hands-on group.
- Students were able to communicate their thoughts better when they worked as a group rather than individually on separate devices.

Finally it was concluded that either approach in interactive electric circuit learning has a positive yield on students' understanding, but the researchers suggest that a combination of both approaches would yield even better learning gains [**24**].

2.1.1.2 Conceptual Understanding of Electrical Circuits in Secondary Vocational Engineering Education: Combining Traditional Instruction with Inquiry Learning in a Virtual Lab (Kollöffel, B. and de Jong, T. ,2013)

According to the researchers of this paper, traditionally engineering and electric circuit education curricula use text-books and hand-on lessons, while these methods are very effective for teaching students terms and definitions, circuit building, or the use of formulas, they do however fall short in providing students with conceptual understanding of the subjects. The purpose of this study is to uncover how to improve the students' ability to conceptually understand the topics. Researchers proposed an inquiry-learning virtual lab environment that would be responsible for improving conceptual understanding. This approach of inquiry-learning should be more effective than solely relying on traditional approaches.

Methodology

The study was conducted on 43 students in secondary vocational engineering. The study was approved by their school board, and their parents. There were two conditions, the traditional learning condition, and the virtual lab one. A between-subjects design was used for this experiment. The courses in the students' curriculum lasted for 3 months. The time span of the experiment was nine weeks, with one session every week.

The experiment had two conditions each with a different learning environment, it's worth mentioning that students in both conditions shared the same course curriculum and textbooks, they only differed in their computer-based learning environment, the learning environments were as follows:

- Traditional learning environment

  The traditional learning environment included the use of a computer-based learning software that was developed and produced by the same company that published the textbook. The software offered a brief summary of the topics discussed for each chapter accompanied with a series of exercises

- Virtual-lab learning environment

  The students participating in this condition were given a virtual lab-based inquiry learning software. The software featured photographic images of the equipment used in the school's practice lab. The students were then presented with different electric circuits throughout the course of the study covering different subjects, those electric circuits were interactive, meaning that students were able to add or remove electrical components, adjust the voltage, and perform measurements across different parts of the circuit (see figure 2.1).

Two knowledge tests were used in this study, a prior knowledge test, and a post test. The tests were used to measure the learning outcomes of students. Both tests contained conceptual and procedural items. The conceptual items required the students to reason about the behavior of current and voltage in different circuits. The procedural items on the other hand handed participants a given circuit and required them to calculate the value of a specific variable.

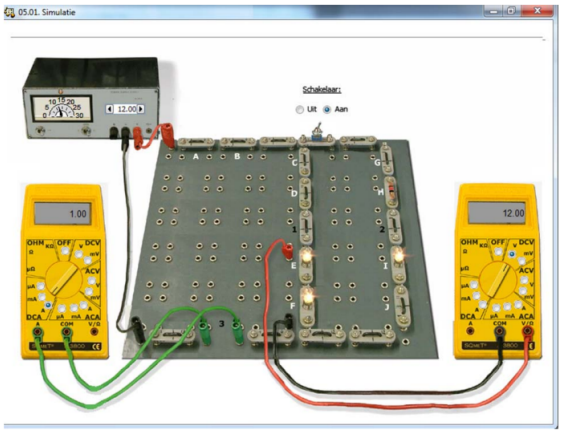


Figure 2.1: Image of the virtual-lab software

The results

Table 2.3: posttest results of the Traditional condition students

	M	S.D	Min	Max
Conceptual test (max. 14)	4.09	1.83	1	9
Procedural test (max. 5)	2.96	0.93	1	5
Total (max. 19)	7.04	1.82	4	12

Table 2.4: posttest results of the Virtual-lab condition students

	M	S.D	Min	Max
Conceptual test (max. 14)	5.35	2.03	1	8
Procedural test (max. 5)	3.65	0.88	2	5
Total (max. 19)	9.00	2.20	5	12

The test results show that the virtual-lab condition students obtained significantly higher overall scores, than the participants in the traditional condition. Virtual-lab students also scored higher on the conceptual items.

Conclusion

Posttest results showed that the virtual-lab students significantly outperformed the traditional students, and that can be observed in both the conceptual skills and the procedural skills. Virtual-lab students were also able to solve more complex problems than their traditional counterparts. It is worth mentioning however that the researchers did not replace practical laboratory activities with the virtual-lab, instead they gave students additional experiences using the virtual-lab software. That is because handling real equipment in the lab is also very necessary.

Finally, based on the previous findings, the researchers suggest that the best for the most benefit, virtual-lab software or inquiry-learning based methods in general should be a part of the students' experience when learning about electric circuits, in addition to their textbooks and practical lab activities [**25**].

2.1.2 Gamification (in education) literature review

2.1.2.1 A Gamification Experience in a Class of a Degree in Engineering. (Ana Júlia Viamonte , 2018)

Gamification as a learning strategy is increasingly discussed in the educational field. It offers a way for engaging and interactive learning making the educational content easily remembered and recalled. Ana Júlia noticed the lack of implementing gamification strategies in higher education. So she started this experiment where gamification strategies were used with the purpose of reducing the school dropout and increasing motivation to achieve better learning and higher passing rate especially with the first year of engineering courses where a large group of students do not attend math classes which leads to higher failure rates.

Methodology:

The implementation of gamification started by replacing the evaluation with points that were collected by students for completing the evaluation components and for their participation in classes online. Students who have become players work to collect points and receive medals, avoid bombs and getting high scores to join the leaderboard.

The students earned experience points for completing a lesson or doing extra research which allowed them to get access to special powers. The special powers allowed the students to eliminate incorrect alternatives from a math test or gain extra lives.if they had enough XP they could buy help on tests. The students who barely registered in the course had a hundred of starting points and everything they did or didn't was giving or taking points from them. There were twenty levels where each hundred points represented a level and the levels were corresponding to grades from zero to twenty.

The medals were reward attributes for performing certain tasks while the bombs were penalty attributes for not preforming certain tasks.

The tests had three difficulty levels: easy, medium and hard. During the semester the students had to do six tests in moodle and to at least one level of each level. With the ability for the students to adjust the difficulty level, earning rewards from passing harder levels and doing extra work, With gamification the tests and exams turned into fighting against enemies and the class work turned into missions which allowed the students to increase their points reaching them to maximum. With this methodology the experiment started.

Results:

In this study the sample was the set of 294 students registered in the first year and first semester in electrotechnical engineering course, the majority were men only 7 % of these students were women.

With gamification the classes had a more challenging experience. There was a very large increase in the attendance numbers of each student. Traditionally in Math classes the attendance is low specially in first year but in that year the classes saw a considerable increase in attendance in both theoretical and practical classes and the rate of students who dropped out was lower than the previous years. See the figure below (figure 2.2):

This experiment was reflected in the final approval rate as the students worked harder during the semester as they wanted to win the game, earning all medals and overcoming the challenges. The percentage of dropout of this course was very low (6%) compared to previous years (15% -30%) the rate of failing was also low (33%)

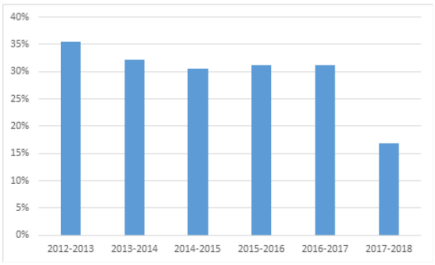


Figure 5. Percentage of students who dropped out in the last years

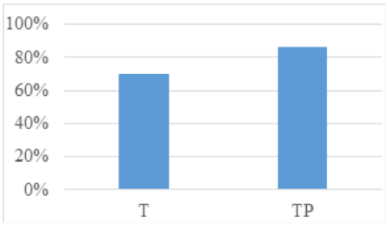


Figure 4. Average attendance with gamification

(a) Percentage of students who dropped last year **(b)** Average attendance with gamification

Figure 2.2: Students survey results

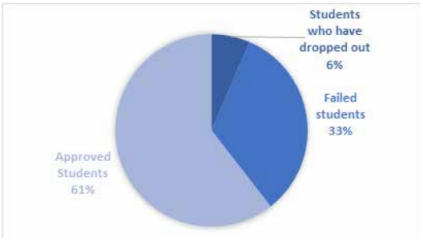


Figure 6. Approval rate

Figure 2.3: Average rate

A survey was made and the advantages and disadvantages were collected from the students showing as following:

Table 2.5: Students Thoughts on the experiment

Advantages	Disadvantages
Motivation and stimulation of learning	Harder than previous year
Development of logical reasoning and problem-solving strategies and challenges.	Over competitive
Competitiveness	Distractions with loss of focus of the content
Self-improvement and persistence.	Increased gambling addiction
Playful and dynamic way of learning	Mechanization: the student plays for playing and not for learning.

Of the students who answered 35% Considered the experiment to be excellent, 42% very good , 20% good and none of the students rated it as a bad or very bad experience.

The results of this research showed an educational success that year which illustrated How the games have a strong physical effect on people's behavior. Making the gamification a valid approach to contribute to the students motivation prompting the students cognitive development. But the true potential of gamification is not easy to obtain as gamification may result in an unattractive and insufficient entertainment experience. That is why It is important to plan the educational objectives, discussing the strategies and analyzing the previous published experiences [**26**].

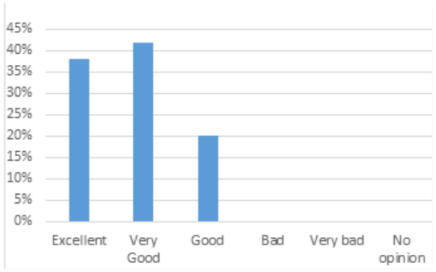


Figure 2.4: The feeling about Gamification on The experiment

2.1.2.2 Electric Circuit Simulator Applying Augmented Reality and Gamification (Vinicio Burgos, César Guevara and Lorena Espinosa , 2021)

Introduction

According to the statistics represented by Educational Evaluation National Institution (EENI) 22.8% of the students form the Andean region and 18.3% from the coast had insufficient grades in areas that include the study of science (Physics, Chemistry and Biology). From this point this Study proposes a solution by developing a physical mobile application That implements the methodologies of gamification and increased reality with the intention of improving creativity and academic performance of the students. The theme of this study focused on the implementing of direct current electric circuits. The proposed application will allow the students to learn and reinforce their knowledge continuously as the functionalities that will make up the application will consist of the ease of building different associations of electric circuits components putting the students in a competitive and challenging environment to solve problems and enhance their knowledge.

Methodology

The learning circuits prototype was developed for the learning of electrical circuits in a series, parallel and mixed way consisting of an application that can be used from any device with data, fixed or mobile. There were countless limitations for carrying out this type of experiment in real laboratories. There is the fact that several institutions do not have the resources to implement them, adding to the risks of bad connections and the thermal effects that are generated or electrical shocks that could happen while experiencing electrical circuits in real life.

The programmatic environment of “Scratch” was chosen to implement the application as it allows to carry out a block of programming in a synthetic, versatile, easily understood way for all users. See the figure 2.5.

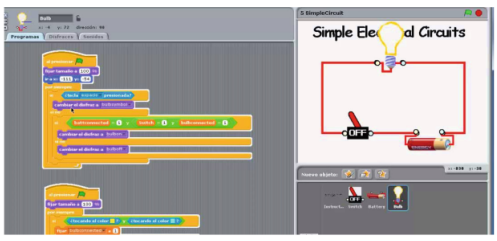


Figure 2.5: Scratch block programmatic environment, with application to the diagramming of electrical circuits

The development of the circuit prototype included:

- Defining the type and quantity of electrical devices that could be included
- Identifying the connection (parallel , serious or mixed).
- Considering the drawing of objects how and will they interact.
- Including the necessary cables and switches, after which the blocks, sentences and appropriate coordinates.
- Declaring the variables and their condition within the chosen scenario.
- Programming of the electrical elements such as lights, LEDs and motors.
- Messages with their respective associated sound signals were included which identified as informative, motivational or safety alerts corresponding to danger or poorly connected circuits.

Results

The results that intended to be achieved from this proposal is improving the learning in circuits and increasing the motivation and creativity of the students leading to a significant advance in understanding the physical phenomenon of the subject leading to increasing the Academic performance of the students.

Conclusion

The Topic of electric circuits was selected Due to the large numbers of the students who have difficulties understanding how the electric circuits work and how the current flows through bulbs or any resistive elements. For this reason it is considered important and relevant to introduce this subject in a fun , playful and entertaining way to achieve better understanding and to motivate students in this experimental science. The proposal shows a way for implementing electrical circuits including all the possibilities that give the students to experiment and learn without the fear of risks that could happen while experimenting in the real world [**27**].

2.2 Case studies

2.2.1 Duolingo

Figure 2.6: case study subject logo (Duolingo)

More than two billion people worldwide are studying a foreign language (Forbes 2019), and digital learning seems to be on the rise for languages, with an estimated revenue around 6 billion dollars, and is expected to be 8.7 billion by 2025. But it's a vast market with lots of players around the globe, and the chance was there for a dominant one.

Duolingo already offers more languages than the competitors, they also include languages that aren't spoken by lots of people, like Hawaiian. So it can always attract more users and new users can find the language they seek to learn. Along with offering more languages to learn, more users prefer duolingo because it's free, compared with other competitors like Rosetta Stone which charges 120 dollars a year. Another competitor, Babble, has an estimated revenue of more that 115 million dollars from its yearly subscription fee of 85 dollars.

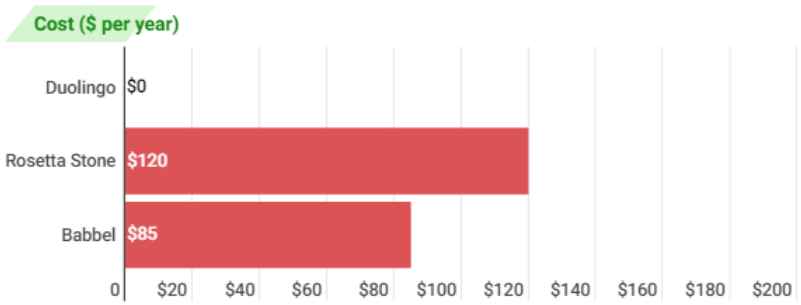


Figure 2.7: Duolingo versus competition: cost

The huge popularity of duolingo isn't just because it's free of charge, that's just one of its many advantages. The app is designed to grab the users and keep them engaged, using gamification elements and tricks, like points, badges, level system, treasure chests and streaks for continuous use of the app. Also, the app has a simple user interface designed to make it easy and effortless.

Duolingo's three-minute lessons are designed to keep the learning experiment easy and approachable. Some of the disadvantages of using duolingo are that it doesn't offer real world training, and that is a pivotal part when it comes to learning languages. Also, according to a study from 2020 some students find using the app boring, although the study also finds that most students disagree when it comes to the app being difficult to use or expensive, it still shows that there's room to improve. [**28**][**29**]

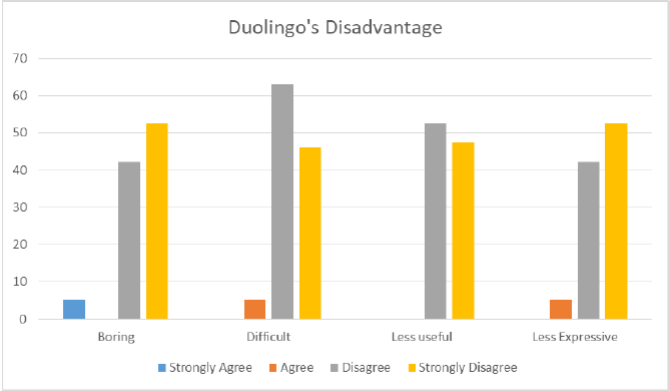


Figure 2.8: Duolingo's disadvantages based on a questionnaire

2.2.2 While True: Learn()

Figure 2.9: case study subject logo(While True: Learn())

Gamification in education can take many shapes and forms, *While True: Learn()*, is more of a game than Duolingo and other educational applications. It teaches machine learning in a fun and easy way, whether you have advanced skills as a data scientist or not it doesn't matter, anyone with basic knowledge of machine learning can play this game and learn a lot from that experience. Throughout the game, users can learn the concept and principles of machine learning and programming gradually. The game has a low bar for beginners that doesn't require them to be experts in the subject. Also, the game has shown from the get go that it has a high engagement rate with players.

With the release of the game, it has achieved more success than ever expected. Selling more than expected by the developers, and in different areas around the world, it had reached a wide variety of audience. Not only that, but at least three schools reported to have already started using the game in their educational process. Also, tech media coverage suggests that a large number of players have applied for machine learning courses and machine learning jobs after playing the game. There are huge advantages of playing this game, for starters you get to experience the concepts of machine learning at a very simplified level. Also, you get to try and learn from your mistakes while playing and try to better implement those concepts every time you play [**30**].

2.2.3 Quizlet

Quizlet

Figure 2.10: case study subject logo (Quizlet)

Much like duolingo, quiz let is an app that helps people to learn languages and test their knowledge of that language. Not only that, Quizlet will also help you learn about any subject in a large number of different fields. Its compact and easy-to-use practice material makes it fun and entertaining to learn about a new subject, whether it's a new language, math, science or even game development.

Quizlet offers a number of different options you can learn about a certain subject, flashcards, which can be used as a helpful memorization tool. Learn, write, spell, match are all different features and ways you can learn and test your knowledge. There's also a "test" feature where you can answer questions based on the subject you 've been learning. A study has found that the majority of users spent around one hour weekly on the app, primarily using the "test" method. Some users spent more than three hours. Most of the users, though, didn't like the "gravity" feature.

Also in this study, we can tell that 95% of users who have used Quizlet think it was a good tool for learning. And that's not a new thing, because students will prefer a more gamified learning experience over the more traditional ones they find at schools. In addition, most students said that

the friendly user interface of the app and the fact that they used different colors to distinguish different terms helps them remember those terms faster.

When it comes to Quizlet's disadvantages, all participants in the study reported that they can encounter some mistakes and errors. Due to the fact that any user can add lessons and publish it for other users to look up without evaluation. Also, most students have said that the app doesn't show flexibility when it comes to the answers, meaning your answer isn't correct unless it matches the answer put down by the one who designed those lessons. Although there's some room for improvement, Quizlet shows that a gamified experience can capture the attention of students more than traditional learning methods. [**31**]

2.3 Project expected outcome and contributions

Thus far, we've introduced the importance of *electric circuit design*, the concepts of *gamification* and *game design*, and the problem with the state of electric circuit education (chapter 1), followed by a thorough literature review of gamification and electric-circuit-design-related research and projects. While there are some promising attempts at gamifying the electric circuit design learning experience, there are still many gaps to be filled (see 2.3); thus, this project's expected outcome is ***to develop an educational puzzle game, whose player can both enjoy an entertaining experience regardless of their scientific interest level, all the while implicitly gaining valuable experience and knowledge in electric circuits design, where they can opt-in for a more academic learning experience through references to external materials, data-sheets, and circuit schematics designed to encourage real-life experimentation, and allow for academic instructors and supervisors to supplement their coursework and practical assignments with select (or all) sections of the game.***

2.3.1 Research contribution and future work

From the research perspective, this project extends the current literature with a new perspective which more heavily employs the concepts of game design relative to previous gamification attempts. Future work may use all the source code and documents from this project to improve on one or more of the following aspects:

- Apply other creative approaches and attempts at game design.
- Experiment with, and/or employ different approaches of gamification.
- Extend to a wider curricular scope.

Chapter 3

System analysis and design

3.1 Proposed software

3.1.1 Functional requirements

Table 3.1: functional requirements

Requirement #	Requirement definition
REQ00	The game will be in 2D.
REQ01	The game will include a collection of electric components.
REQ02	The player will be able to drag and drop the components.
REQ03	The game will feature puzzle-style levels.
REQ04	Each level will have a goal to complete.
REQ05	The player will progress by finishing levels.
REQ06	The levels will follow a hierarchical tree-structure.
REQ07	The level-topics will follow standard electric circuit introductory curriculum structure.
REQ08	The game must be able to simulate electric circuits.

3.1.2 Non-functional requirements

Table 3.2: functional requirements

Requirement #	Requirement definition
REQ00	The game should provide descriptive messages on failure.
REQ01	The game must be fun.
REQ02	The game could feature illustrative animations.
REQ03	The game must feature a user-friendly interface.
REQ04	The game should be suitable for: electric circuits students.
REQ05	The game must be educational
REQ06	The game should be suitable for: electric circuits hobbyists.
REQ07	The game should be suitable for: anyone that enjoys puzzle games.

3.2 System Architecture

The game will run on the unity game engine utilising a lot of its features. As for the simulation of the circuits the we will use the C# library SpiceSharp. SpiceSharp is a circuits simulation library that is compatible with the Berkeley Spice simulator. The player will interact with the game through its user interface, those interactions could be navigational interactions to transition from one menu or scene to another, or they could be gameplay interactions when playing a level. Then in order to complete a level the player needs to achieve some goals that are introduced at the beginning of the level. The circuits submitted by the player is then simulated using SpiceSharp and the results are sent back to the game, the game then decides whether the goals were achieved or not.

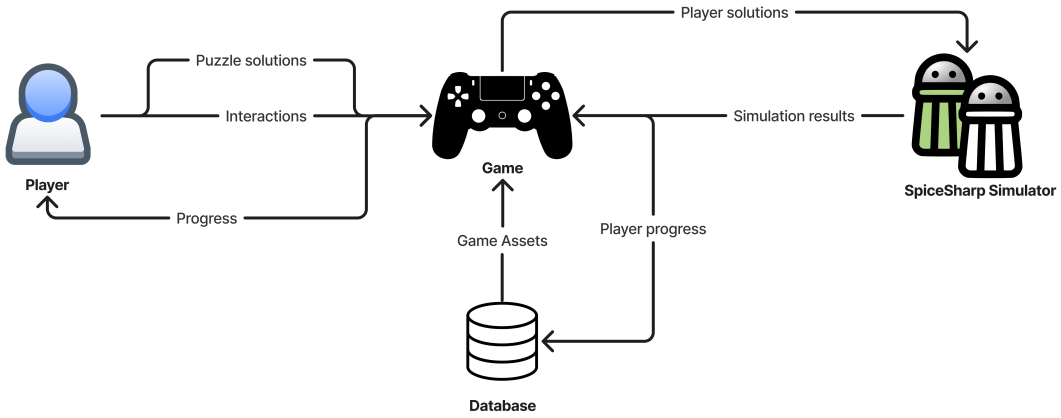


Figure 3.1: System Design & Architecture.png

3.3 system analysis

3.3.1 Context Diagram

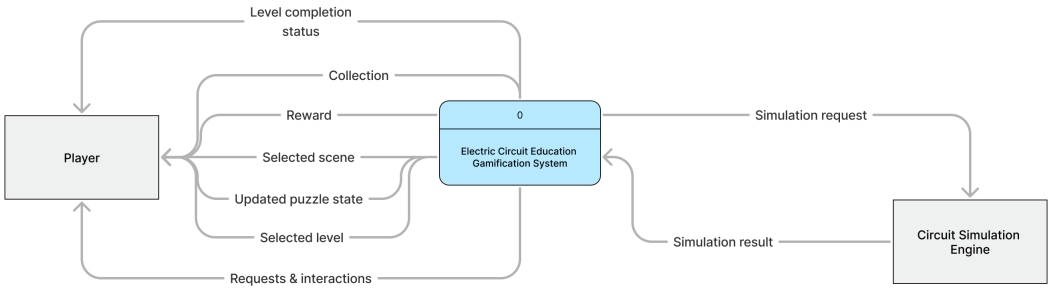


Figure 3.2: Context Diagram

3.3.2 Process Diagram

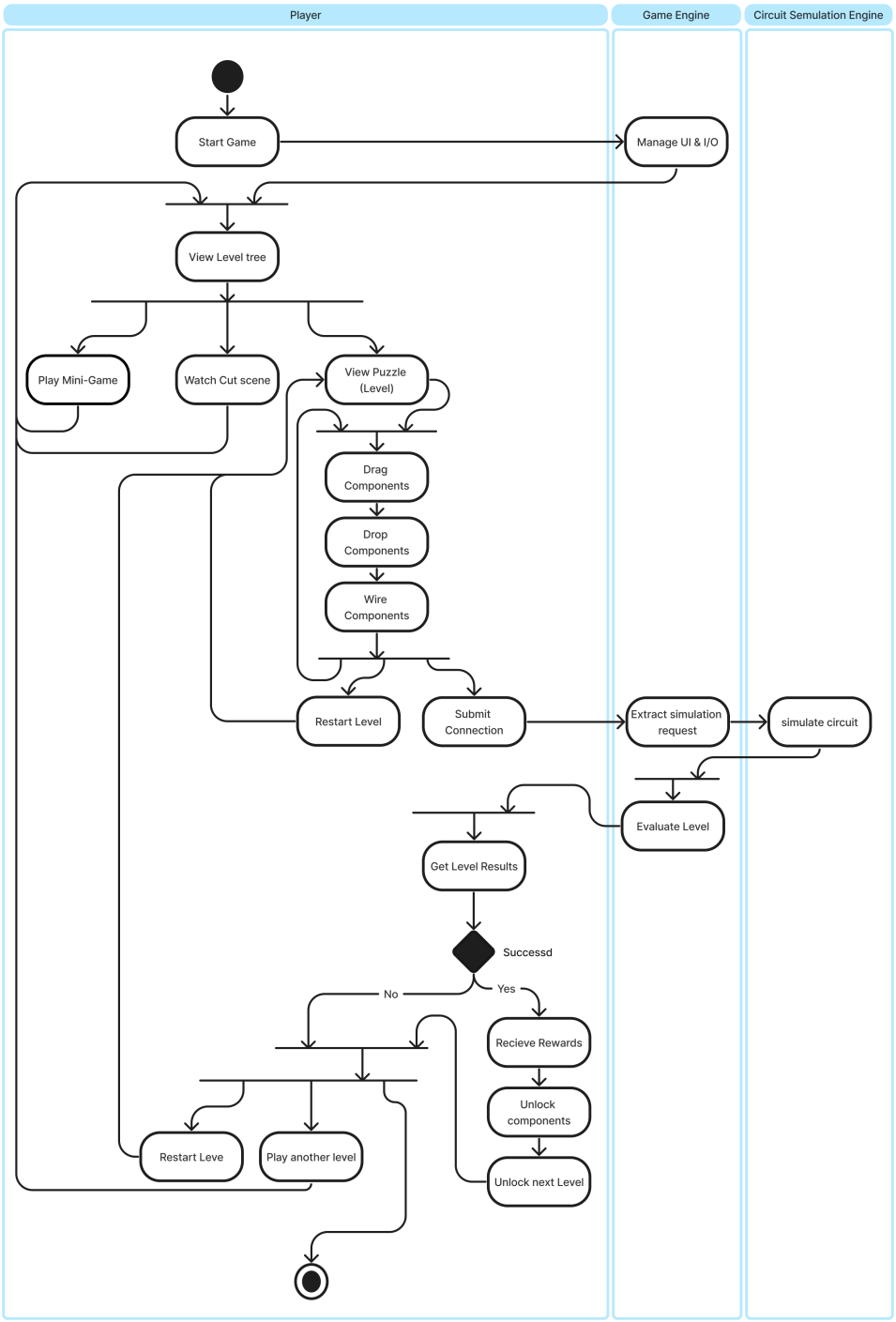


Figure 3.3: Process Diagram

3.3.3 Use Case Diagram

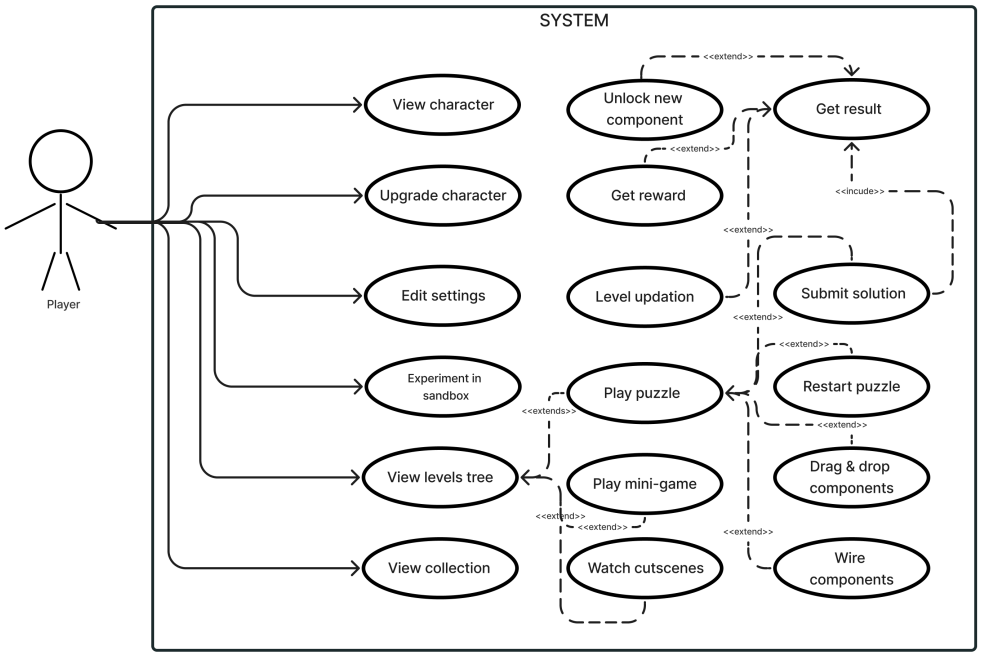


Figure 3.4: Usecase Diagram

3.3.4 Data-Flow Diagram

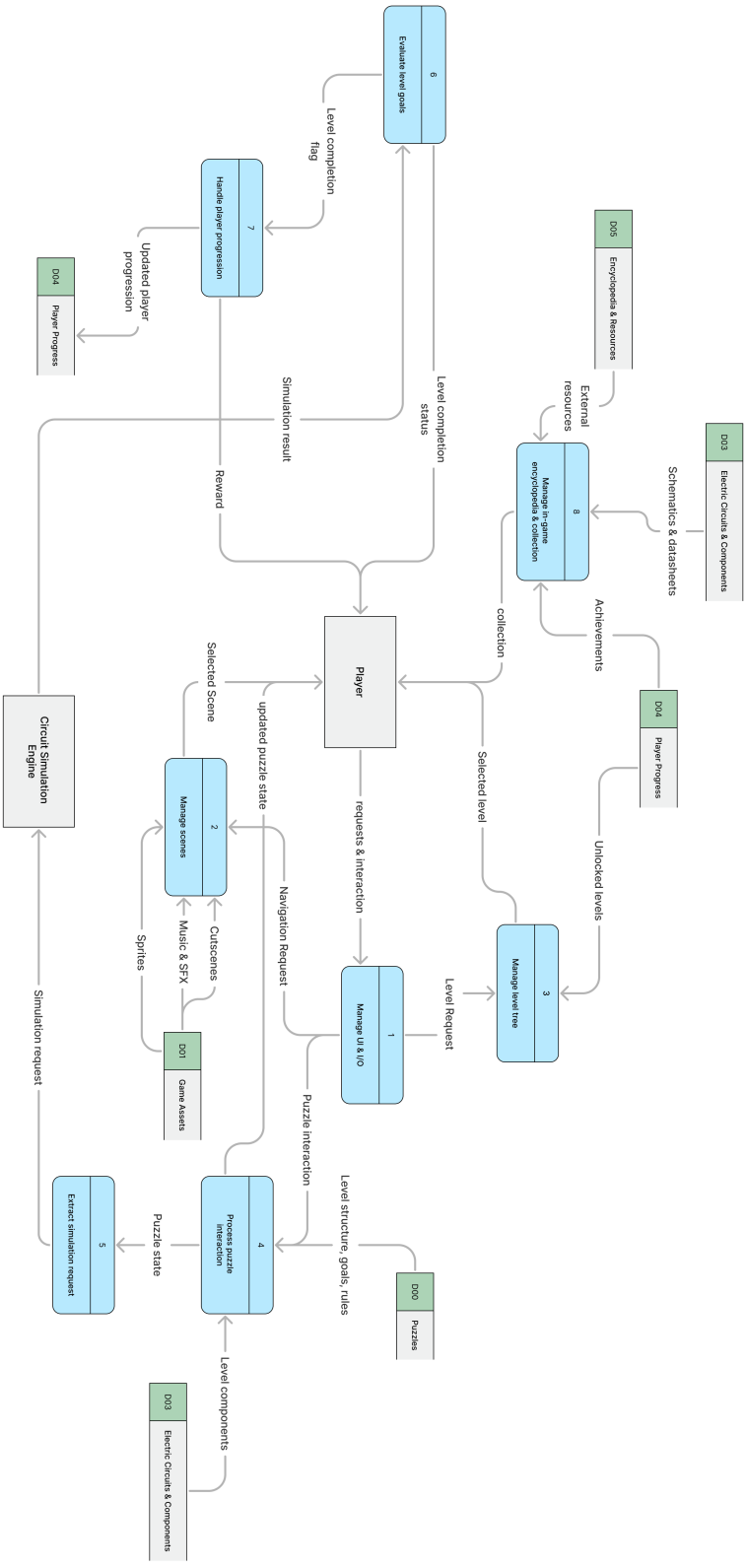


Figure 3.5: Data-Flow Diagram

3.3.5 Sequence Diagram

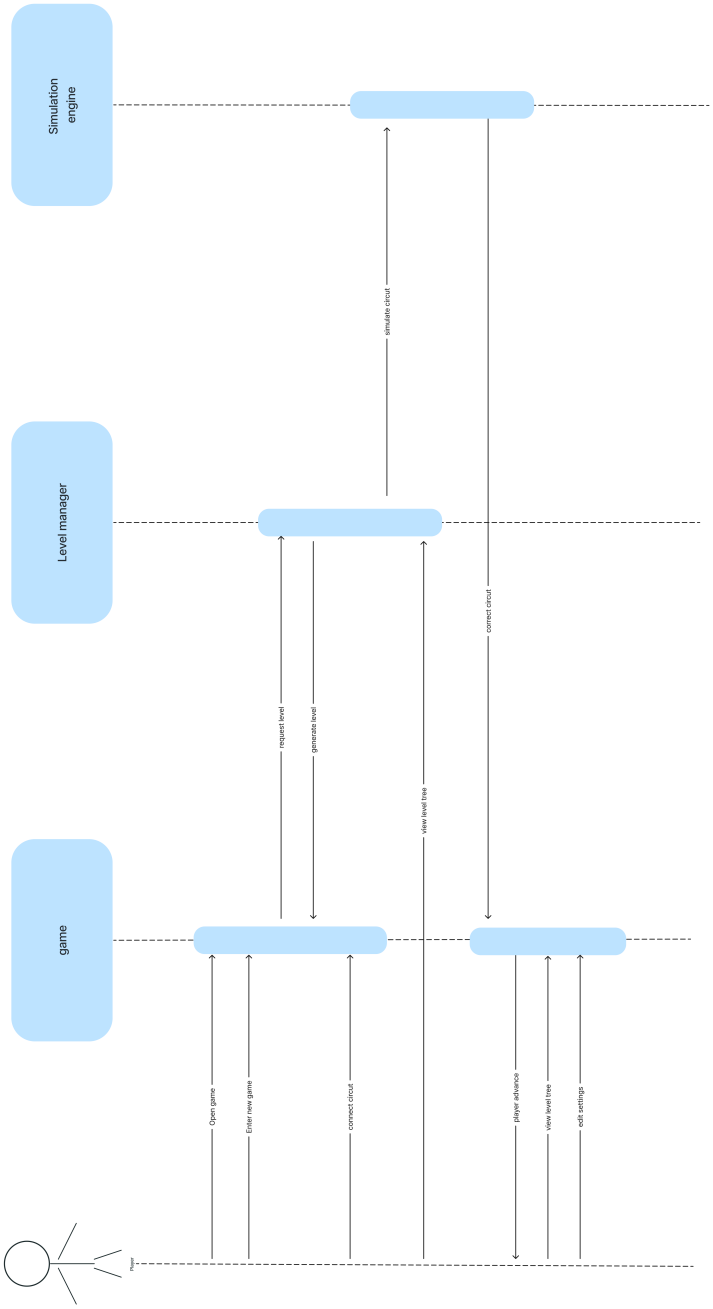


Figure 3.6: Sequence Diagram

3.3.6 Class Diagram

3.3.6.1 Simulator and Simulation Manager

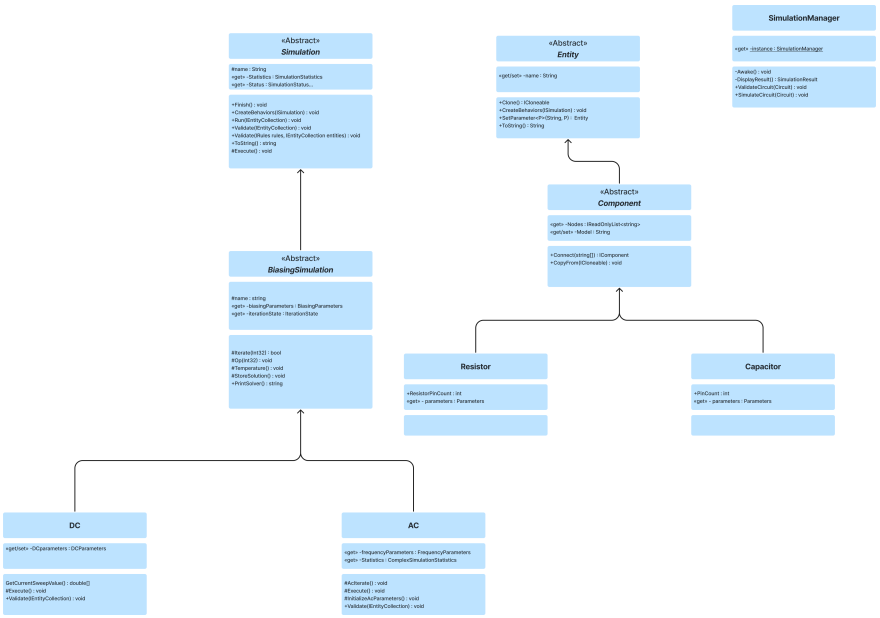


Figure 3.7: Simulator and Simulation Manager Class Diagram

3.3.6.2 GameComponents and ComponentManager

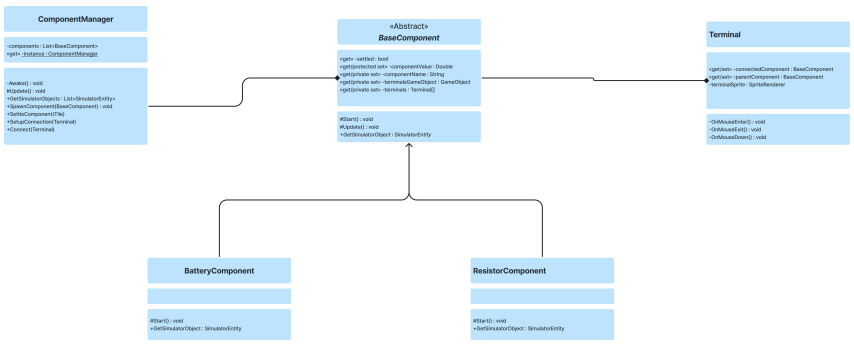


Figure 3.8: GameComponents and ComponentManager Class Diagram

3.3.6.3 GameManager

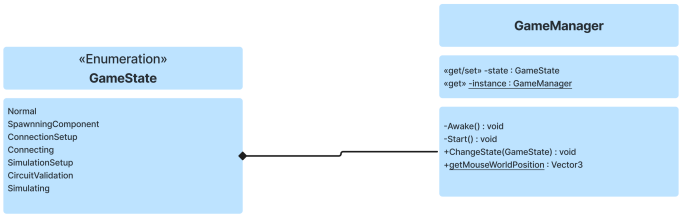


Figure 3.9: GameManager Class Diagram

3.3.7 Entity Relation Diagram

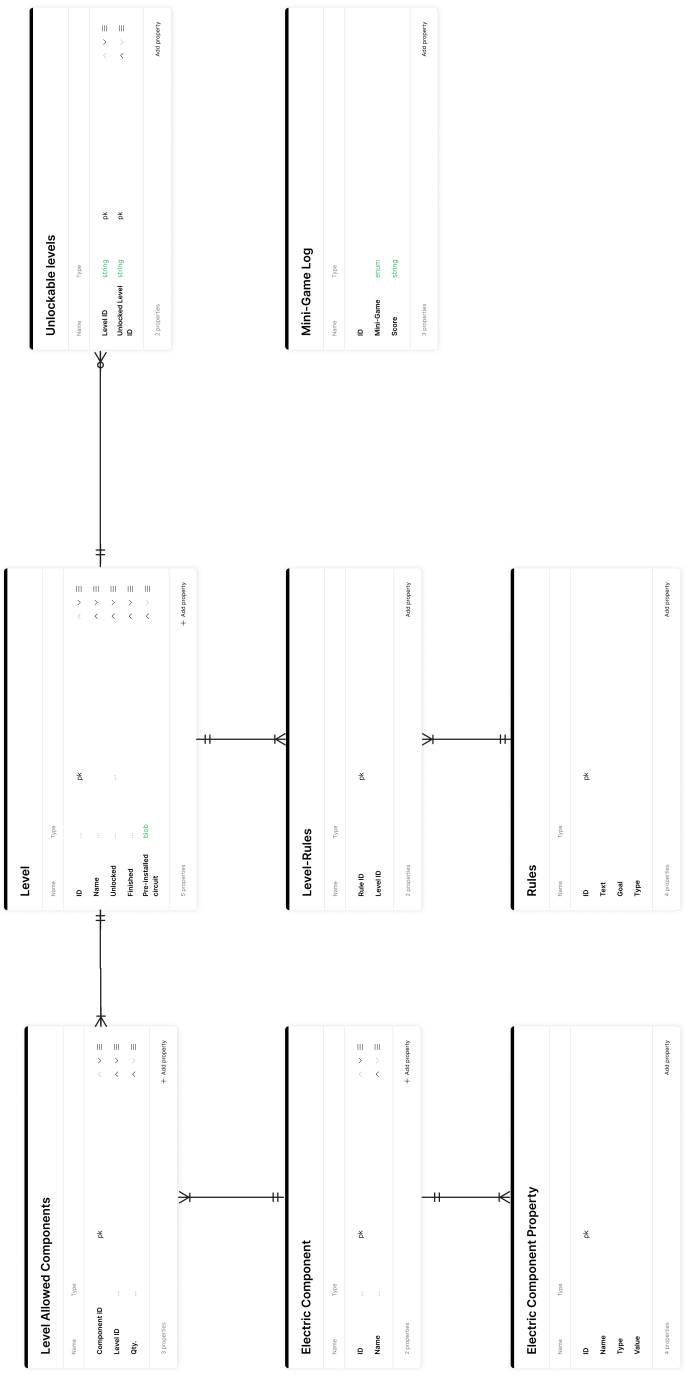


Figure 3.10: Entity Relation Diagram

3.3.8 State Chart Diagram

3.3.8.1 Drag and drop components

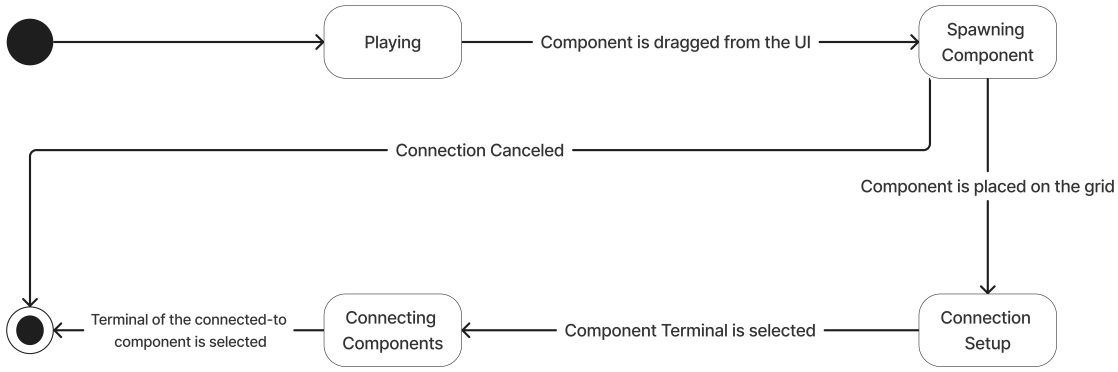


Figure 3.11: Drag and Drop Components State Chart

3.3.8.2 Simulate Circuits

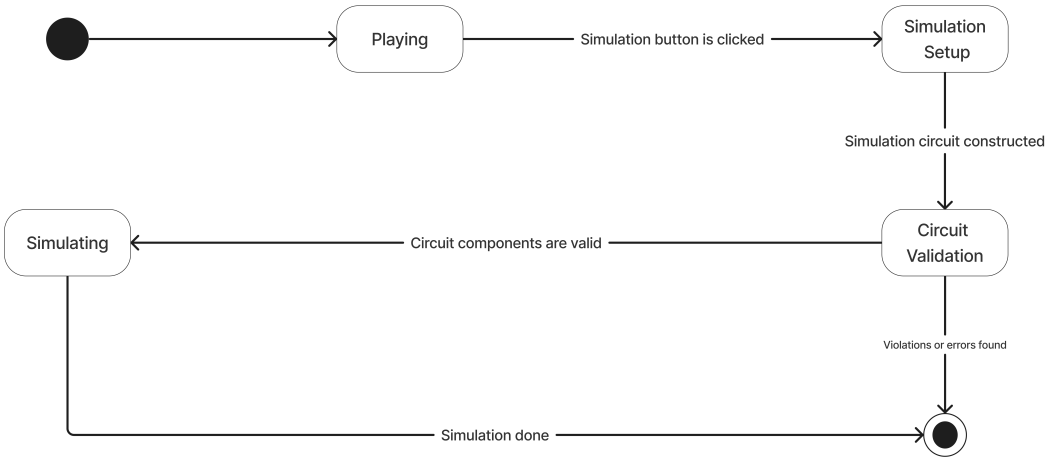


Figure 3.12: Simulate Circuits State Chart

3.4 Methodologies

3.4.1 Software development life cycle (SDLC)

Software development life cycle (SDLC) is the process followed by developers when they are building a product. It consists of several phases, and each one is essential to the process of creating a high quality software. The life cycle describes the methodology the team follows in the overall development process.

Stage 1: planning and requirement analysis

This stage is the cornerstone for the whole process of building a software. In this stage, the planning for the system is done by the heads of the team, to define the project scope, set the goals and objectives of the system, and determine the risk associated with the project. The information collected is then used to plan the project approach.

Stage 2: defining requirements

Once the first stage is done, a system analysis is conducted to determine and document the requirements of the system and get them approved by the stakeholders. Also, we will analyze the requirements to determine the characteristics of the system.

Stage 3: designing the product architecture

Based on the requirement specification, we will design the system architecture for the development process. Usually, more than one design is proposed and shown to the stakeholders to agree on which is the best one for the product.

Stage 4: development

In this stage of the SDLC, the actual programming of the systems begins, based on the system architecture designed in the previous stage. The programmers should be able to develop the system without much hassle if the previous stages of development are done correctly.

Stage 5: Testing

After the development is done, the system gets tested for bugs and errors, although testing is done simultaneously with every stage of the SDLC, in this stage the system is tested as a whole the reported bugs get fixed and re-tested.

Stage 6: Deployment

Once the system is tested and ready to be published, it gets released in the market, sometimes a product will be deployed in stages and sometimes as a whole. After the deployment of the system and the users feedback, the product may receive updates to enhance the performance or fix any bugs found by the users.

Although games are basically software, the SDLC is not suitable for game development, so we will follow Game development life cycle (GDLC) in the making of this project. Which is more suited for game development. Also following methodologies like the waterfall model.

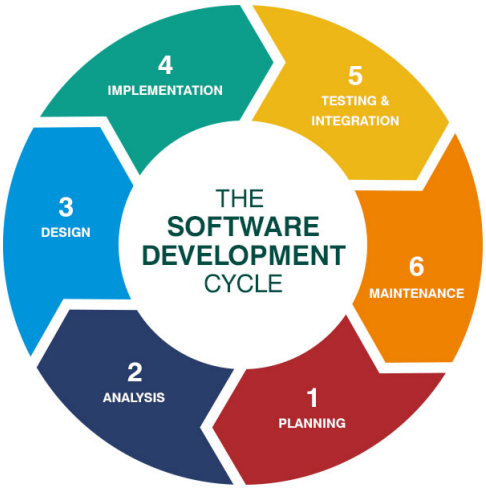


Figure 3.13: Software Development Life Cycle (SDLC)

3.4.2 Game development stages and the game development life cycle (GDLC)

Video games are in their essence software; depending on the scale of the game, project management and orchestration play a fundamental role in development. Games with poor project management are more likely to run over budget and time estimates, as well as contain a large number of bugs. However, unlike other kinds of software, games are not suitable for the typical software development life cycle (SDLC), but rather follow agile-like methodologies modified to suit the game development life cycle (GDLC), which goes roughly as follows for most games:

Pre-production stage

Also known as the planning phase (or both, combined into one stage), this is when the game's initial and basic properties are specified. It is intended as a feasibility study of the game idea, followed by prototypes and documents, which can later be presented as proof-of-concept. This stage is mainly focused on idea and concept development, as well as documentation. Its goals are typically some or all of the following:

- Develop and document game concepts, ideas, mechanics.
- Produce game descriptions and concept art.
- Write a proposal document if the game is to be sold to a publisher.
- Write a concept document, including comprehensive information such as: the game's genre, gameplay description, features, setting, story, target audience, hardware platforms, estimated schedule, marketing analysis, team requirements, and risk analysis.
- Write a Game design document (GDD) , a document which describes the game's concept and major gameplay elements in detail. It may include concept art for the game, story plot, theme and colors, initial level design sketches, and may even be accompanied by a functional prototype for some of the game mechanics. This document is a living document, that is, the first version is produced in the pre-production stage, then the document is updated on weekly or even daily-basis during the production stage.
- Produce quick functional prototypes for select game mechanics.

Production stage

This is where the majority of the game's development time, effort, and budget is spent. The entire development team is involved in this stage; artists, engineers, designers, musicians, writers, and many other talents will collaborate to bring the game together. This stage can take anywhere from a few months or less, to 10 or more years, depending on the scale of the game.

Testing stage

This stage most of the time does not fall in linear progression relative to the GDLC, but rather segments of the game go back and forth between production and testing. Test types vary and there are several game tester roles, varying from bug testing and stress testing, to gameplay, balance, and fun-factor testing. Several milestone releases of the game can go public during the production-testing cycle; alpha and beta versions of the game may go to public testing before the game moves to the next stage.

Launch stage

At this point, the game has been full-developed and tested, and is ready for the official launch. This stage is typically accompanied by game polishing, bug fixes, advertising and creating launch trailers and other publishing media, readying the game for launch and distribution.

Post-production stage

This stage involves bug fixes, game patches (balancing, minor content updates, etc. . .), and new content additions. New content might start off an entire new GDLC if it's large enough.

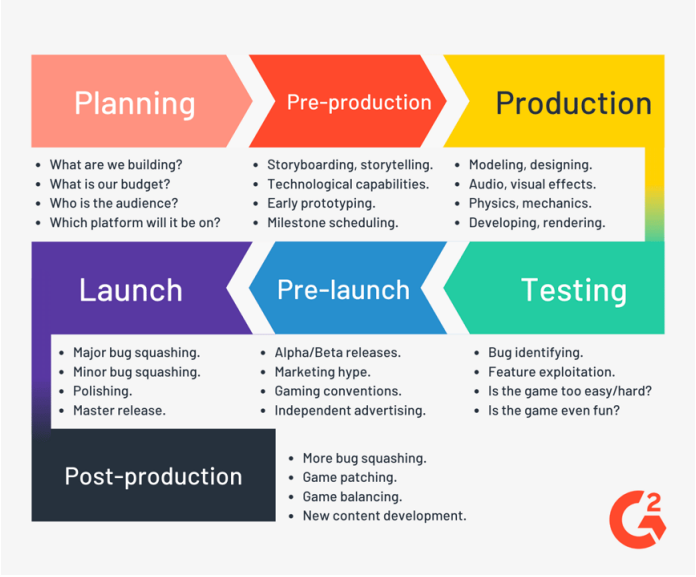


Figure 3.14: Example game development life cycle (GDLC) from G2

This stage involves bug fixes, game patches (balancing, minor content updates, etc. . .), and new content additions. New content might start off an entire new GDLC if it's large enough. That all being said, an insightful research literature review (Aleem et al., 2016) [**11**] also shows that despite the fact that a proper GDLC will help a game organization identify its strengths and weaknesses and provide guidance for improvement, the domain is still fragmented and lacks standard good practices relative to its typical SDLC counterpart.

3.5 Algorithms

3.5.1 System Tools

3.5.1.1 Programming languages:

- C#

3.5.1.2 Frameworks:

- .NET framework: .Net Framework is a software development platform for building and running Windows applications. The .Net framework consists of developer tools, programming languages, and libraries to build desktop and web applications. It is also used to build websites, web services, and games.

3.5.1.3 Tools:

- Unity: Unity is a cross-platform game engine developed by Unity Technologies used to build games. Unity provides game developers with a 2D and 3D platform to create video games.
- SpiceSharp: Circuit simulator used to simulate the results of each circuit in the levels.
- Figma: Used for designing the game UI and art.
- Git: Git is a free and open source distributed version control system designed to handle everything from small to very large projects with speed and efficiency.
- IDEs: Visual Studio Code