DC Circuit Simulator

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# Analysis

## Background and problem

St Peters is a local secondary school that covers Key Stage 3 and Key Stage 4 education for students aged 11 – 16 as they prepare for their GCSEs at the end of Year 11. They are a Church of England school located in Exeter and educates over 1000 students.

Elliot is a Year 10 student at this school with various learning difficulties, including dyslexia, that make it difficult for him to read out of a textbook or sit down and concentrate for long periods of time on work and often requires movement breaks to make school more manageable. At the moment he is struggling to grasp the various topics as part of his GCSE Physics curriculum more specifically electricity and circuits. He prefers to be able to get hands on and learn by doing along with visual examples rather than learning out of a book, of which he finds boring and tiresome, so he is currently looking for a tool that will allow him to have more of an intuitive and visual understanding of circuits and how they function. Especially, parallel and series circuits specifically.

In order to make these concepts more digestible I will be making a DC circuit simulator in the form of a website. Where the user is able to get hands on experience tinkering and constructing various circuits from a list of components making the learning more interactable and hopefully more enjoyable. The website will also be able to provide visual feedback of the various properties of each component such as: resistance, amperage, and potential difference in order to provide a visual display of how the components and circuits interacts with the end goal of making the topic more intuitive.

Learning about electricity and circuits can be challenging for many students, particularly those who find it difficult to understand abstract concepts from a textbook. This is where the DC circuit simulator, an interactive learning tool, can be incredibly useful. By creating a website that allows students to experiment with circuits in a hands on way will allow students like Elliot to unlock a natural curiosity and fascination with the topic potentially impacting their choices and encouraging a more academic route towards further education.

One of the most difficult aspects of Physics as a subject is the fact that a lot of topics can be very abstract and hard to visualise. This is where a simulator can be particularly useful. The advantages of a website simulator over a physical circuit is that by providing students with the ability to see each components internal properties they will be able to get a deeper understanding of the relationships between amperage, resistance and potential difference rather than having to interpret equations. In addition the simulator provides a safe learning environment and allows students to see how the changes they make to their circuits affects the circuit as a whole. This will be very beneficial to not just students that struggle with abstracts concepts and reading out of a textbook, but also encourage students who are academically strong to be more curious and engage with the content even more. This is because students learn best when they are passionate about the subjects they’re studying.

## Users and their needs

### End users

The end users will be accessible to anyone who wishes to use it but is specifically targeted at any students and potentially teachers wanting to use the simulator as an additional tool to enhance the learning of GCSE electricity and its concepts. These students may have a variety of unique preferences to how they learn, the style they learn and different levels of their own knowledge when approaching the topic. In order to make the simulator website engaging and effective for a range of different students, it may be necessary to consider different levels of difficulty or complexity for the circuits, as well as providing different resources or explanations to support the simulator so that the students understand what exactly the simulator is teaching them. For example it’s one thing to see a wire have 5 amps but the student may not know what 5 amps is.

### Interview

Q: What do you like about the current system with regards to learn the electricity topic?

A: It’s simple and you can experiment with things to see if they work.

Q: What do you find most difficult when learning about electricity and circuits?

A: The broad abstract concepts and having to read textbooks with dyslexia.

Q: What do you not like about the current system?

A: Not clear what the components are or how to use menus.

Q: What are the most important features you would like to see in the new system?

A: The ability to inspect each component within the circuit.

Q: What is your preferred way to learn?

A: Visually and practically and being read things allowed.

Q: Do you think that the new system will help with learning about electricity?

A: Yes.

Q: Are there any features you want to see in the new system?

A: Audio and explanations of why things would or wouldn’t work.

Q: Are there any other comments or ideas for the new system?

A: No.

### User requirements

In order for the new system to be implemented successfully there are various design choices that need to be considered. To meet the needs of the user the following requirements should be considered:

The backend of the simulator: the website should be designed in a way that allows for easy modification and addition of new components and features through the integration of various modular aspects of the code. The simulator should be able to handle different types of circuits, that allow users to experiment with different combinations of components. Additionally, the backend should be designed in a way that allows for easy maintenance and potential updates to the website.

User interface: the user interface of the simulator should be design to be intuitive and easy to use. Users should be able to select and drag components from a menu, and connect them together on a grid to form a circuit. Additionally, the user interface should provide real time feedback on the properties of each component, such as resistance, amperage, and potential difference, so that users can see the effect of their changes in real time.

Menu options: The simulator should provide a range of menu options that allow them to select different components and customise their circuits. For example, users should be able to choose between batteries, lightbulbs, wires, and switches. Additionally, the simulator should provide menu options that allow users to change the voltage of the battery, and individual components resistances to see how those effect the current of the circuit.

Visual design: the visual design of the simulator should be clean, modern, and easy to navigate. The website should be designed with the end user in mind during the whole of development, and should provide a visually engaging appealing experience that encourages user experimentation with circuits hopefully making learning more fun.

Accessibility: the website should be designed to be accessible for users with different levels of knowledge and different learning styles.

## SMART Objectives

## MVP (Minimum Viable Product)

* + 1. There should be circuit components.
       1. There should be a battery.
       2. There should be a wire.
       3. There should be a lever (switch).
    2. Circuits should be made up of connected components.
       1. Circuit manipulation should be done through manipulating a graph data structure.
       2. Connecting components should be done through manipulating a linked list data structure.
    3. Circuits should be displayed on a grid on a HTML page.
       1. There should be menus in order to select components and place them on the grid.
    4. Circuit components should have properties: resistance, amperage, potential difference.
    5. Components properties should be manipulated dependent on components they’re connected to and with accordance to calculations and physics equations.
       1. Algorithms to detect if the circuit is a closed loop.
       2. Appropriate algorithms to determine resistance and potential difference and amperage of each component.
       3. Simulate the flow of current through the circuit by using a directed graph.
    6. Components properties should be displayed on a HTML page in an intuitive way.
    7. Components properties should be stored and retrieved in a database (MongoDB atlas) and manipulating components properties directly links to manipulating the values within the database.

## Extension

* + 1. There should be other components such as: lightbulbs, capacitors, variable resistors and diodes each with their own corresponding properties.
    2. The website should have an intuitive styled design using CSS and bootstrap.
    3. The user should be able to log in and save circuits to their account within the database.

## Modelling the problem

The current system that the new system will be improving upon is from the website:

<https://www.physicsclassroom.com/Physics-Interactives/Electric-Circuits/Circuit-Builder/Circuit-Builder-Interactive>

A picture containing chart

Description automatically generatedThe current system has a basic interface where you can select the different components to be placed on the lines of the grid. The current system provides the following components: wire, resistor, filament lightbulb, and ammeter. As you can see in the image on the left, none of the components have any labels. This makes it difficult to know what each component is making it harder to search it up and learn more about it and learn how it functions, unless you already know what it is. For example, I did not know what the component on the far right was until I randomly stumbled across a tool that identifies what each component is. However, this tool is in my opinion unintuitive to use and was hidden under an unrelated menu.

Diagram

Description automatically generated with medium confidenceChart

Description automatically generated with medium confidenceThe next menu initially, I thought was simply a menu to change the voltage of the battery. However, after some messing around I’ve realised that it is a menu to adjust the variables at each component. As you can see in the images on the left. I believe that this is unitivitive and a poor design but could be easily fixed with good form design and labelling which I hope to address in my new system.

A picture containing diagram

Description automatically generatedThe last menu provides a voltmeter and ammeter that can be placed at the junctions of the grid to provide a reading. However, the ammeter in this menu is easy to accidentally place in parallel to the circuit which can provide the wrong values for circuit. This may end up confusing students using the current system.

One thing that the current system does well is that at each junction is states the potential difference at that junction. There is also animations of charge flowing around the circuit which can provide an intuitive understanding of the conventional way to imagine current flowing around a circuit. As well as this, the filament light bulbs provide a light when current is flowing through them. The light also increases and decreases depending on the amount of the current flowing through the lamp.

In the new system it may not be possible to include all these niceties and animations due to time constraints and the other functionality that I hope to include. If there is time these additional animations may be attempted to be added as they are a good way to make the electricity topic more visually intuitive for the students.

# Design

The design below is the design of the final system. Within the technical solution section there were other prototypes that were developed but did not make it into the final design so are not included here.

## Overall System Design

### Front End

The new system will be made up of a frontend and a backend. The frontend will be the part of the system that the end user actually interacts with. The frontend will be a website that can be accessed by anyone with an internet connection. The new system will have a list of components on the left-hand side of the screen as well as a sign-up button. There will be a grid in the centre of that takes up most of the screen this will be the sandbox area for the circuits to be built.

front end html css or jquery reactjs

web api bridge between front end and back end

backend python or nodejs

database mysql

css tricks

The front end will be a HTML page styled using bootstrap CSS and consist of moveable components powered by Jquerey

<https://www.itsolutionstuff.com/post/node-js-express-form-submission-exampleexample.html>

<https://www.digitalocean.com/community/tutorials/how-to-use-web-forms-in-a-flask-application>

https://css-tricks.com/snippets/css/complete-guide-grid/

### Back End

The backend will be made up of various different components. These will include the C# algorithms that actually handles the simulation and a database to store details on the users that sign up to the website.

The back end will be made using the express framework for node.js server which is then connected to a MongoDB database. This database will be interfaced using the Mongoose framework which will simplify and ease database integration. The node.js server will be responsible for circuit manipulation and simulation calculations.

## Data Dictionary

## Pseudocode

## Class Definitions

## User Interface Design

## Security and Integrity

# Solution

There were various prototypes throughout development that did not make it into the final project so I have separated up the document to include each iteration of the technical solution.

## Attempt one

For the first attempt at the solution I decided to use HTML5 a

## Attempt two

## Attempt three

# Testing

Throughout development of my technical solution, I used an industry practice for software development called TDD (testing driven development) by using a testing framework for JavaScript called Jasmine. Jasmine allows you to write specs which are pieces of code that tests other pieces of code by running this piece of code and comparing the actual output to an expected output and then provides useful error messages if the test fails. This allowed me to test each part of code as I developed it in order to find out that all parts of the solution worked as they were developed. Otherwise, I wouldn’t know if half of my code worked until integrating all the systems together integration itself can cause plenty of bugs itself let alone bugs in the algorithms themselves. The alternative would be the laborious task of manually tracing algorithms during development which is also prone to more human error. I believe that although development was slower and more meticulous this overall has saved a lot of time.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test | Test Spec | Test Type | Test Description | Test Outcome | Expected Outcome |
| 1 | Wire | Normal | Wire object has correct default values when instantiated. | Success | Success |
| 2 | Battery | Normal | Battery object has correct default values (different to wires defaults) | Success | Success |
| 3 | Lever | Normal | Lever object has correct default values when instantiated. | Success | Success |
| 4 | Lever | Normal | Lever has a method onClick which alternates the levers isOn Boolean value. | Success | Success |
| 5 | LinkedList | Normal | LinkedList has a head node and default length of 0 when instantiated. | Success | Success |
| 6 | LinkedList | Normal | LinkedList method insertFirst pushes a new node onto the head of the data structure and increments the length of the linked list. | Success | Success |
| 7 | LinkedList | Normal | LinkedList method insertLast adds a new node to the end of the data structure and increments the length of the linked list. | Success | Success |
| 8 | LinkedList | Erroneous | LinkedList method insertAt attempts to insert a node at an index outside of the length of the linked list but fails. | Success | Success |
| 9 | LinkedList | Boundary | LinkedList method insertAt attempts to insert a node at the start of the linked list and increments the length. | Success | Success |
| 10 | LinkedList | Normal | LinkedList method insertAt attempts to insert a node at the provided index in the linked list and increments the length. | Success | Success |
| 11 | LinkedList | Normal | LinkedList method getAt returns the data associated to the node in the data structure at the index provided. | Success | Success |
| 12 | LinkedList | Erroneous | LinkedList method getAt attempts to retrieve data at an index outside the length of the linked list and fails. | Success | Success |
| 13 | LinkedList | Erroneous | LinkedList method removeAt attempts to remove a node outside the length of the linked list and fails. | Success | Success |
| 14 | LinkedList | Boundary | LinkedList method removeAt removes the node at the head from the linked list and moves the head to the next node and decrements the length of the linked list. | Success | Success |
| 15 | LinkedList | Normal | LinkedList method removeAt removes the node at the index provided and decrements the length of the linked list. | Success | Success |
| 16 | LinkedList | Normal | LinkedList method clearList sets the head of the linked list to null and sets length to 0. | Success | Success |
| 17 | LinkedList | Normal | LinkedList method search returns the data associated to the node at the index provided. | Success | Success |
| 18 | LinkedList | Normal | LinkedList method remove removes the node with the data associated to the input of the method. | Success | Success |
| 19 | Graph | Normal | Graph has an empty linked list of vertices and a length of 0 when instantiated. | Success | Success |
| 20 | Graph | Normal | Graph method addVertex adds a vertex to the graph as well as instantiating an adjacency list as a linked list and increments the length of the graph. | Success | Success |
| 21 | Graph | Normal | Graph method addEdge checks if the vertices inputted exist then adds the index of one vertex to the adjacency list of the second vertex. | Success | Success |
| 22 | Graph | Normal | Graph method removeEdge checks if the target edge exists then removes the edge from the adjacency list. | Success | Success |
| 23 | Graph | Normal | Graph method removeVertex loops through all vertices adjacency list removing the edges of the vertex that is to be removed then removes the vertex from the graph and decrements the length. | Success | Success |

# Evaluation

I do not think that I have managed to produce an MVP over the course of the project. I believe the over ambitiousness along with the lack of knowledge and experience hindered me from completing the project to the best of my ability. One month was dedicated just to research in the best solution to the problem, however due to the specific nature of the problem and lack of experience knowing the correct buzzwords to use to effectively search for the information I needed in order to complete the project was extremely difficult. Another month was lost to the original design I had finally settled on attempting relying on solely front end which not only would have been inefficient and messy but also lack any database at all. It was extremely difficult to know how much time to dedicate to attempting one solution and calling it quits. If I were to have stuck with one solution, I always run the risk of hitting a dead end and not finishing the project, on the other hand if I attempted a new solution I then have to start a new with less time. Finally, I had settled on a more ambitious more efficient solution that uses many practices from industry level software developers such as the jasmine testing environment I used throughout the development of the solution. Unfortunately, I came across a difficult logical problem to solve that to my disappointment took two months to finally come up with a viable solution at which point I was left with very little time to complete the rest of the project. In hindsight it would have been smart to divert my efforts into developing the frontend or database while I had hit that snag in the backend. However in the moment it felt as though without that problem overcome I could not continue on to the rest of the project. I believe that if I had not had these setbacks than the project would have been a lot more complete and impressive due to the extra time I would have had to continue development. I would argue that the project or at least the solution I chose to implement for my the project was way above A level standard and had it been completed would have scored top marks.