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 and 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 and visual examples rather than learning out of a book, of which he finds boring and tiresome, so he is currently looking for a tool to make 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 they 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 hopefully making the topic more intuitive.

There are two main problems that the new system will attempt to solve. One, making the electricity topic for AS level physics more intuitive to understand. Two, improve the limited functionality that the current system provides.

The first problem I hope to address through the various tools and functionality of the new system. The new system will be able to perform useful calculations as well as displaying different IV characteristics for the components. The teacher will also be able to create a classroom where they can invite their students. This will be done to increase the tools usefulness within classrooms and when lesson planning. This virtual classroom will allow for the teacher to example circuits, that shows off concepts relevant to the lesson, around to the students in the classroom. Then the students will have the opportunity to play around with the circuit changing specific aspects and hopefully build the intuitive understanding through getting hands on experience seeing how the circuits responds to variations.

The second problem will again be solved by adding new tools and functionality to the new system that the old one lacks. At the moment the old system only contains a very limited number of components not all of which are obvious what components they are. Limited components means that the overall usefulness of the system is low as there is not that much that can be learned from it. My new system will not only contain more components with hopefully a more intuitive way of using the system, but also be able to perform various calculations on the circuits where appropriate such as calculating the emf of a cell or a voltage of a component.

## Users and their needs

### End users

The new system will be a website accessible by anyone and can be used without making an account. However certain features will only be accessible by those who have an account. When making an account you will need to select if you want to make a teacher or a student account. The teacher and student accounts will have the same functionality when it comes to the circuit simulator. However, the teacher account will be able to create a classroom to which they can invite students to. They will then be able to send circuits to the students for them to view and play around with. If there is time, I’d like to make a system that allows the teacher to make problems using circuits that the students will then need to solve. These problems would take the form of having limited access to a set number of components and then must arrange the components in such a way that it meets some criteria such as the voltmeter giving a specific output for example.

### Interview

Q: Would you use the current system to assist in teaching the electricity topic?

A: Yes

Q: What features do you like about the current system or what does the current system do well?

A: I like the value of electrical potential at each junction and after each element. Also, the positive direction of conventional current. I also like the voltmeter and how they can be placed.

Q: What features do you not like or problems with the current system?

A: It is not clear how to place the ammeter in series and lots of students will probably put it in parallel and get a wrong value.

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

A: More components such as diodes, thermistors and LDRs.

Q: Are there any processes or calculations you would like done by the new system?

(for example, showing the iv characteristic of a filament lamp or calculating the voltage at different parts of the circuit)

A: No, I think those should be done by hand with the data collected.

Q: What is the most difficult part of the electricity topic for students usually?

A: Understanding the concept of potential difference. Potential dividers. Internal resistance.

Q: Do you have any ideas on how the new system could help the students understand these parts of the topic?

(for example, some visual way of showing current flowing or resistance increasing as current increases)

A: Visual way of showing how much energy per coulomb the charge has on each part of the circuit (relates to potential and potential difference) and how much energy per unit charge is transferred to the circuit elements.

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

A: No.

### User requirements

The new system should be able to provide a grid-based circuit simulator. This simulator should provide the ability to place components along the lines of the grid. At each junction on the grid there should be the ability to see the potential difference and current. At each component there should be the ability to see the resistance. The user will need to be able to sign into an account to save different circuit pre-sets however, it should not be a requirement to login to an account to use the simulator.

## 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 of the components have any labels. This makes it difficult to know what each component is and potentially search it up and learn more about it, unless you already know what it is. For example, I did not know what the component on the 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, as mentioned in the interview 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

## Database Design

## Pseudocode

## Class Definitions

## User Interface Design

## Security and Integrity

# 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 my 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.