The Well of Maxwell

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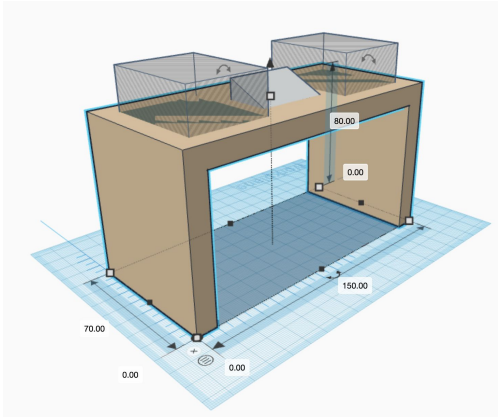
Use-case and requirements

Problem: E&M is difficult, but also useful, and highly integrated in our daily lives

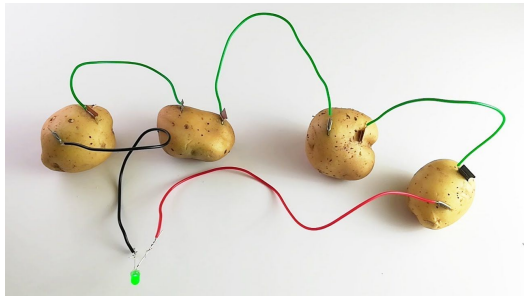
Solution: Teach students the fundamental laws of electromagnetism through an interactive booth housing 2 **circuit demonstrations** and a **web app** interface with gamified components

Goal: Teach aspiring students electromagnetics in a **fun**, **visual** and **effective** way to provide intuition and inspiration for further study

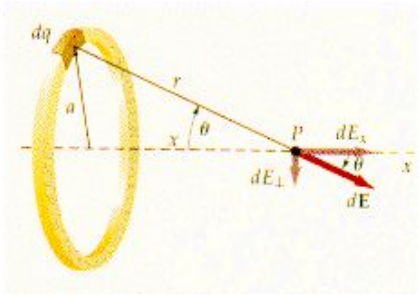


Solution Approach

What inspired everyone here to become an engineer?



VS



$$dE_x = \frac{kdq}{r^2}\cos\theta = \frac{kdq}{r^2}\frac{x}{r} = \frac{kxdq}{\left(x^2+a^2\right)^{3/2}} \quad where$$

$$r^2 = x^2 + a^2 \quad and \quad \cos\theta = \frac{x}{r} = \frac{x}{\sqrt{x^2+a^2}}$$

We now integrate, noting that r and x are constant for all points on the ring:

$$E_x = \int \frac{kxdq}{\left(x^2+a^2\right)^{3/2}} = \frac{kx}{\left(x^2+a^2\right)^{3/2}} \int dq = \frac{kxQ}{\left(x^2+a^2\right)^{3/2}}$$

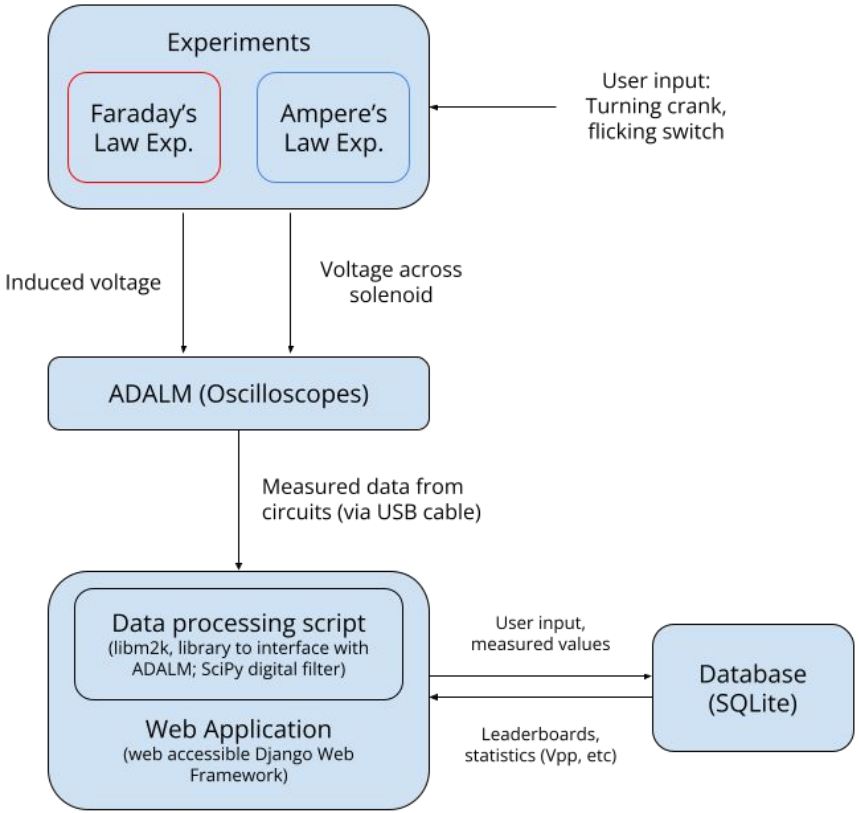
Education: Teach and inspire

Safety: Ensure learning happens in a safe environment

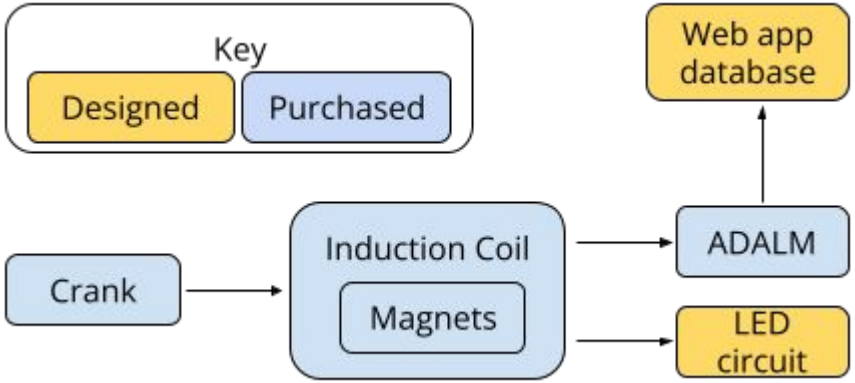
Equity: Provide access to any student

System Specification

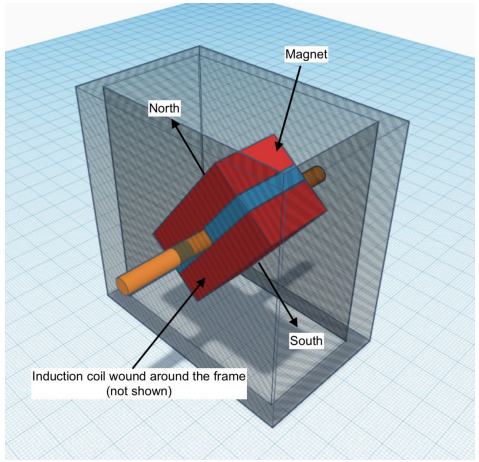
- Faraday's Experiment
- Ampere-Maxwell Experiment
- Web Application



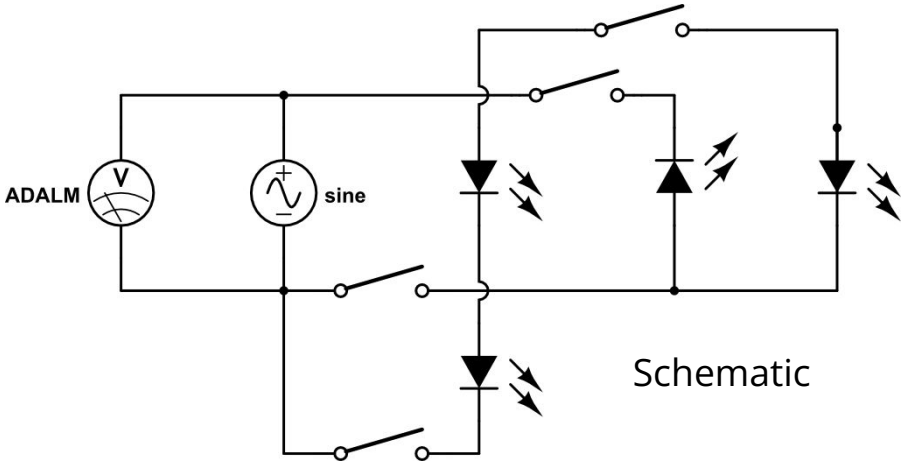
Faraday's Law Experiment



Block diagram

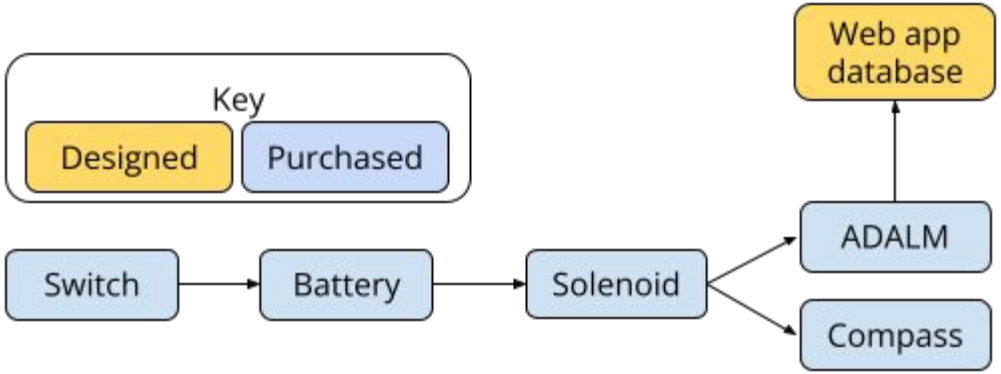


Generator



Schematic

Ampere-Maxwell's Law Experiment



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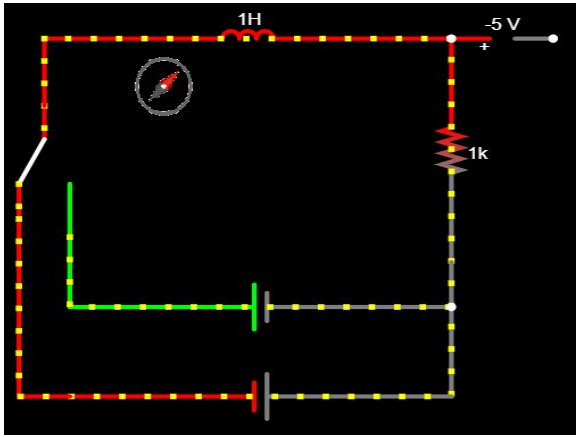
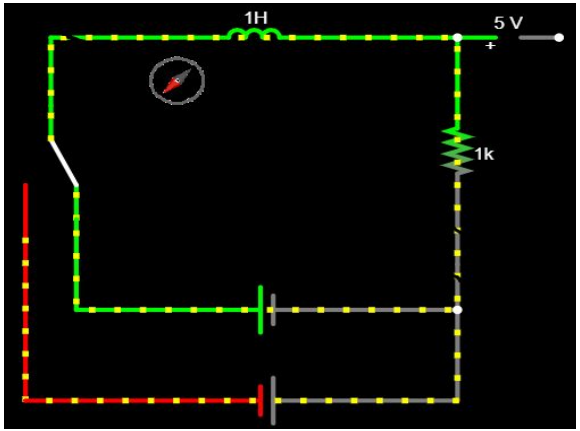
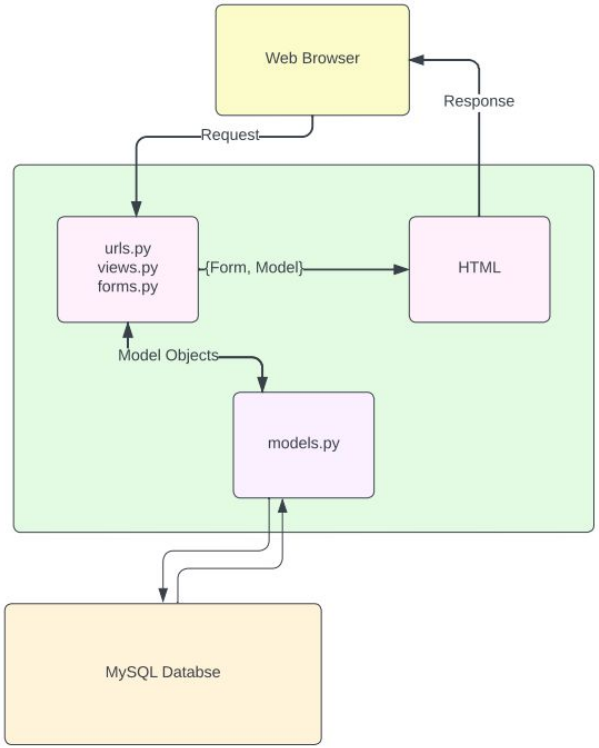
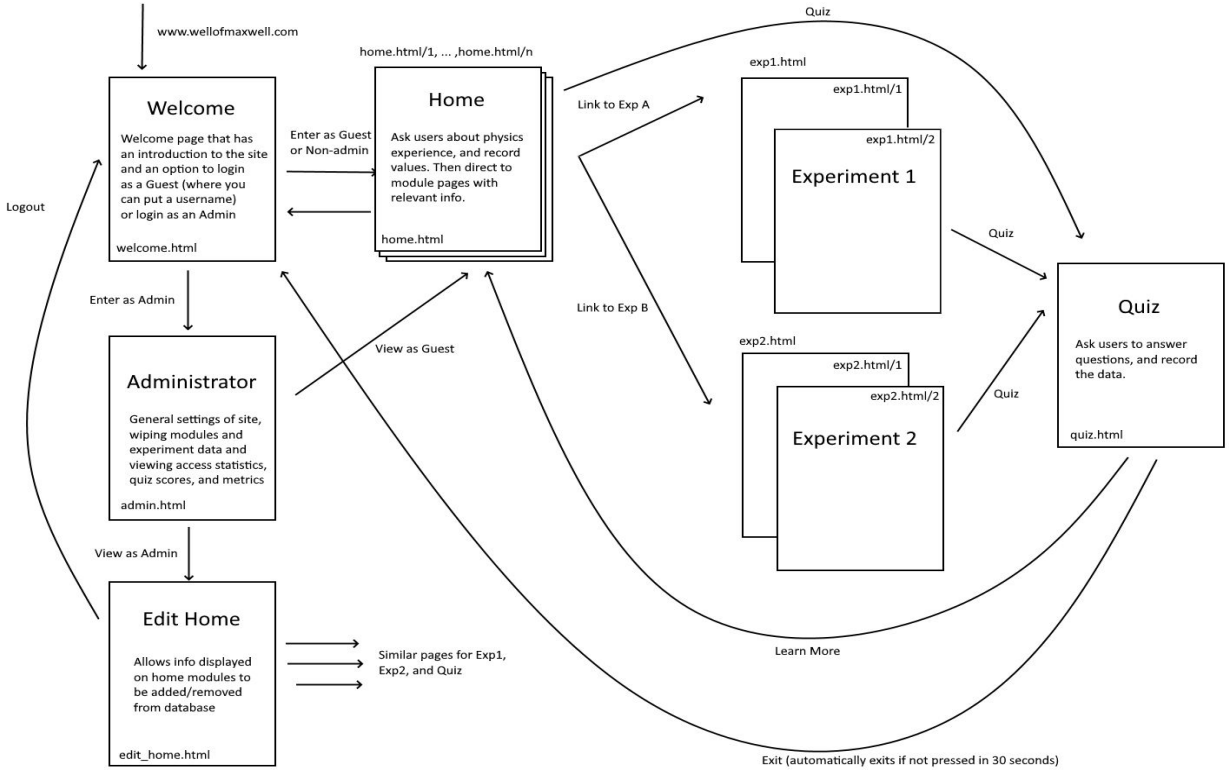




Web Interface





Quantitative Requirements

Requirement	Metrics
Accuracy of measurements	3% error max
Low Latency	< 1s between user input and display
Repeatability & Reusability	Can be safely used by >1000 individuals

Design trade-offs

Key: Selected | Not selected

Oscilloscope - How to measure induced emf?		
Options	Pros	Cons
Arduino	Smaller size	Worse performance
ADALM	Better resolution, accuracy	Harder to integrate (requires the esoteric **libm2k** library)

Faraday's law experiment - How to induce an emf?		
Options	Pros	Cons
Rotation	- Easier to induce high voltage - More fun!	Difficult to design
Linear movement	Easier to design and implement	Induces lower voltage (insufficient to light LEDs)

Design trade-offs

Key: Selected | Not selected

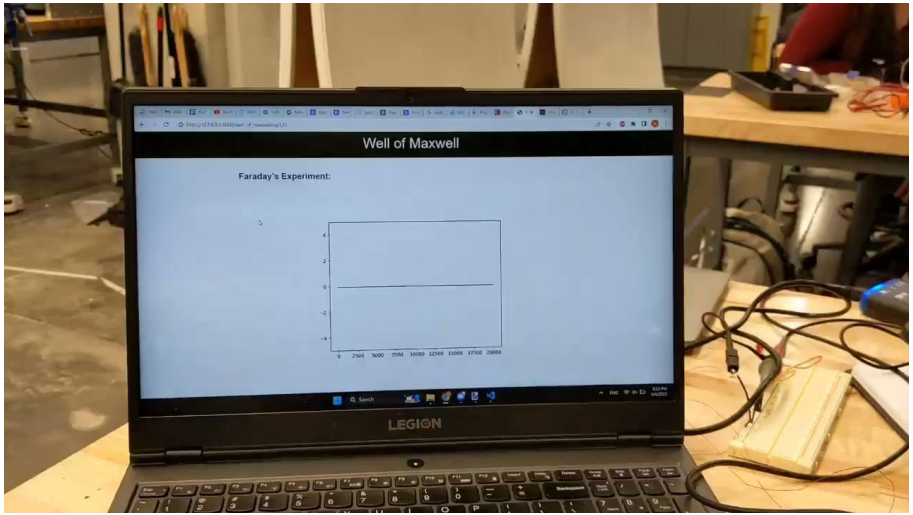
Ampere Experiment - How to show the magnetic field?		
Options	Pro	Con
Permanent Magnet	Easier to explain	No “natural” orientation
Compass	Returns to magnetic north	Harder to explain

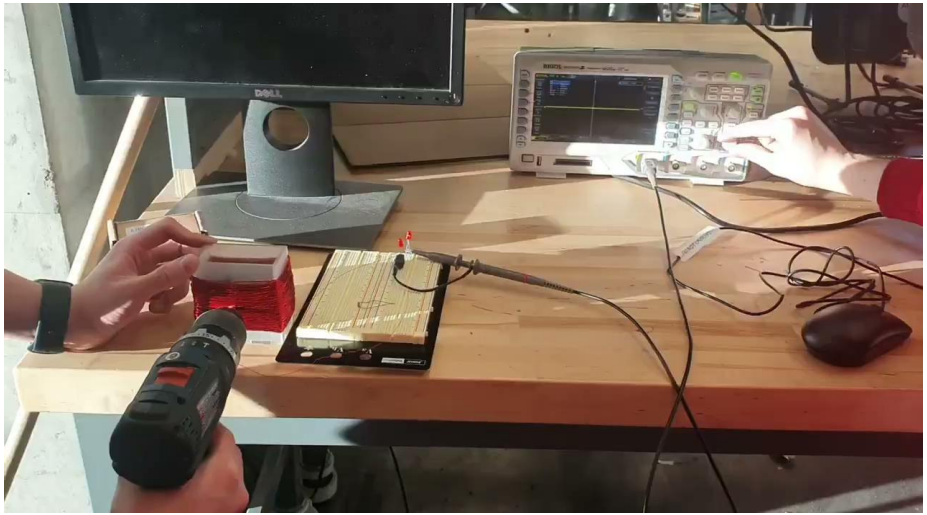
Web Application - What framework to use for development?		
Options	Pro	Con
Django	Dynamic HTML Pages	Less flexibility
Flask	Greater flexibility	More support for static pages

Verification of Design Requirements

Specification	Test	Passing criteria	Performance
Accuracy of measurement	Compared maximum voltage readings on web app with oscilloscope measurements	**±3%** error max	Recorded a max error of **2.37%**
Low latency	Compared the time taken between circuit input and web app animation update	Update occurs in **< 1 Sec**	Average update occurred in **0.92 Sec**
Repeatability & Reusability	Rotated the magnets in the Faraday's law experiment with a power drill for 3 minutes	- LED functions normally - Experiment remains operable	Passed

Verification of Design Requirements

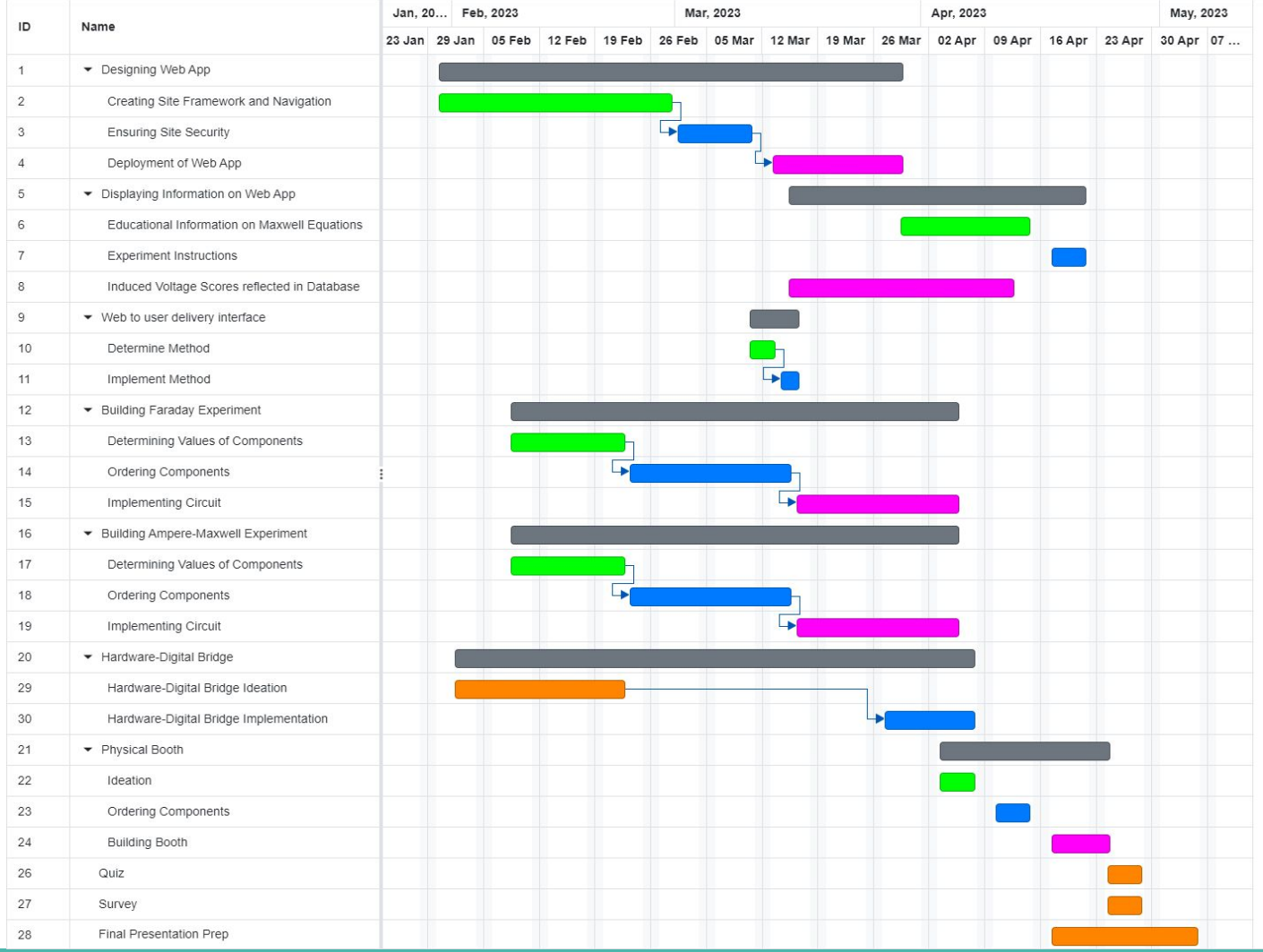




Validation of Use-Case Requirements

Specification	Test	Passing criteria	Performance
Isolation of electrical components from users	Visual inspection	One cannot access the wires, LEDs, batteries, etc., inside the cases	Passed
Surfaces are easy to clean and sanitize to prevent the spread of germs	Visual inspection	No grooves, slots, and other areas that are hard to clean can be found	Passed
Accessible fonts for people with dyslexia	Visual inspection	Consistent usage of accessible fonts [1] (e.g. sans serif) in web app modules	Passed
User satisfaction	Survey after reading modules and trying experiments	Average experience rating of >4.5 / 5	TBD
Learning outcomes	Quiz at the end of the modules in the web app	Average score of >90% on the quizzes	TBD

Project Management



It is not knowledge, but the act of learning, not possession
but the act of getting there, which grants the greatest enjoyment.
– Carl Friedrich Gauss