*"One must **learn by doing** the thing, for though you think you know it – you have no certainty, until you try."*
– Sophocles

The Well of Maxwell

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Product Pitch

The Well of Maxwell is an educational system that teaches people the fundamental laws of **electromagnetism** (E&M) in an intuitive, effective, and interactive manner through a booth housing two **circuit demonstrations** and a **web application** interface with gamified components. The two circuit demonstrations include:

- **Faraday's Law Experiment** - Demonstrates how a changing magnetic field induces an electromotive force (EMF) by letting a user spin magnets housed inside a coil of wire and turn on **LEDs**, which act as **visual indicators** of the strength of the EMF. The user can also learn basic circuit laws by observing the effects of the states of the switches on the LEDs.
- **Ampere's Law Experiment** - Demonstrates how an electrical current generates a magnetic field by letting a user change the direction of current flowing into an electromagnet with a switch. A **compass** and a **galvanometer** are used as **intuitive visual indicators** of the magnetic field and the current, respectively.

The web application displays voltage measurements and plots associated with the state of the experiments, while also providing **educational modules** and **gamified quizzes** of varying difficulty levels to appeal to a larger audience.

System Architecture

The overall system consists of 3 components: Faraday's law experiment, Ampere's law experiment and the web application.
To bridge the circuits to the web application, we use the ADALM oscilloscopes to read voltage data from both experiments and feed it to the web application.

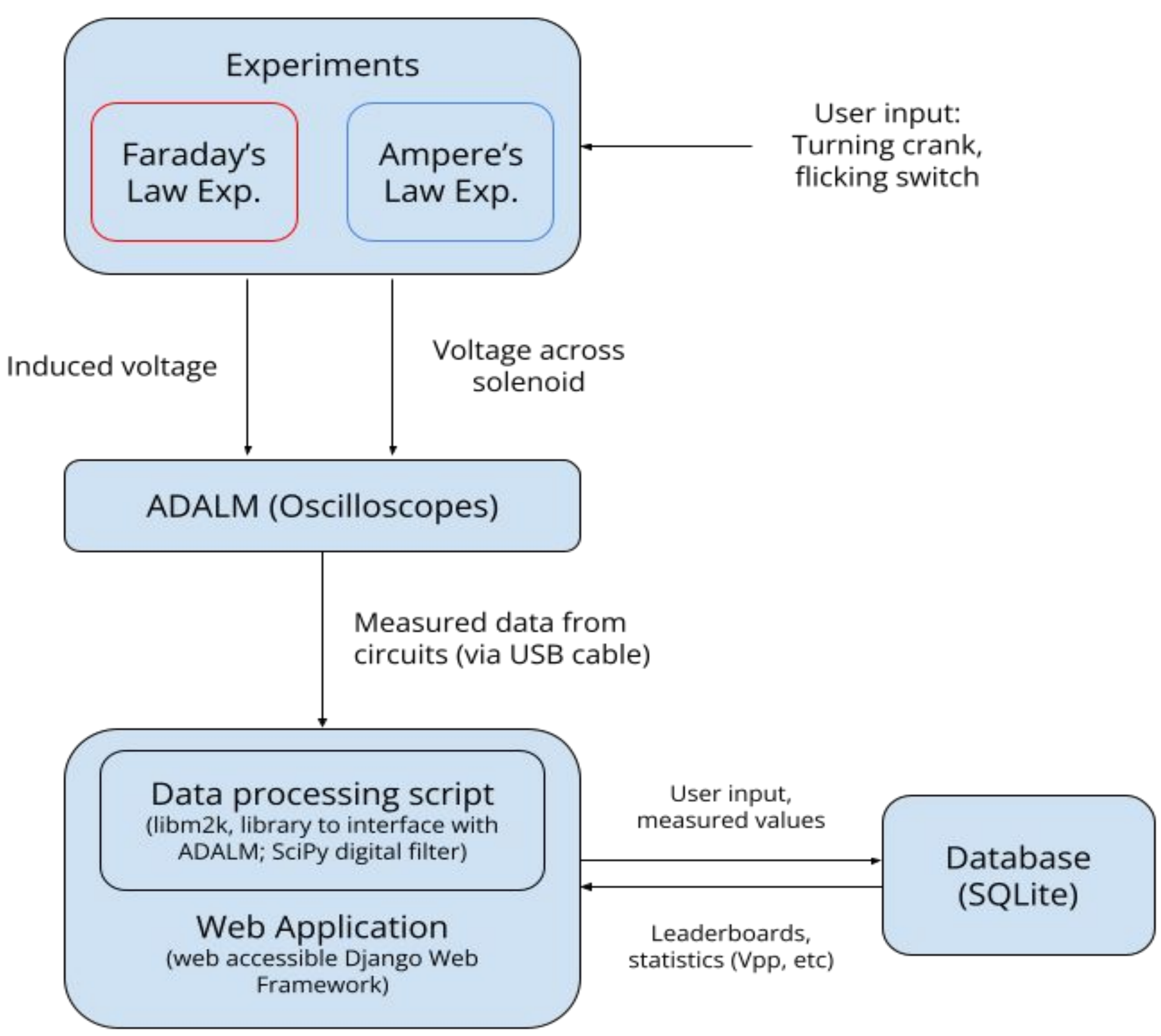


Fig. 1: Overall Block Diagram

Conclusions & Additional Information

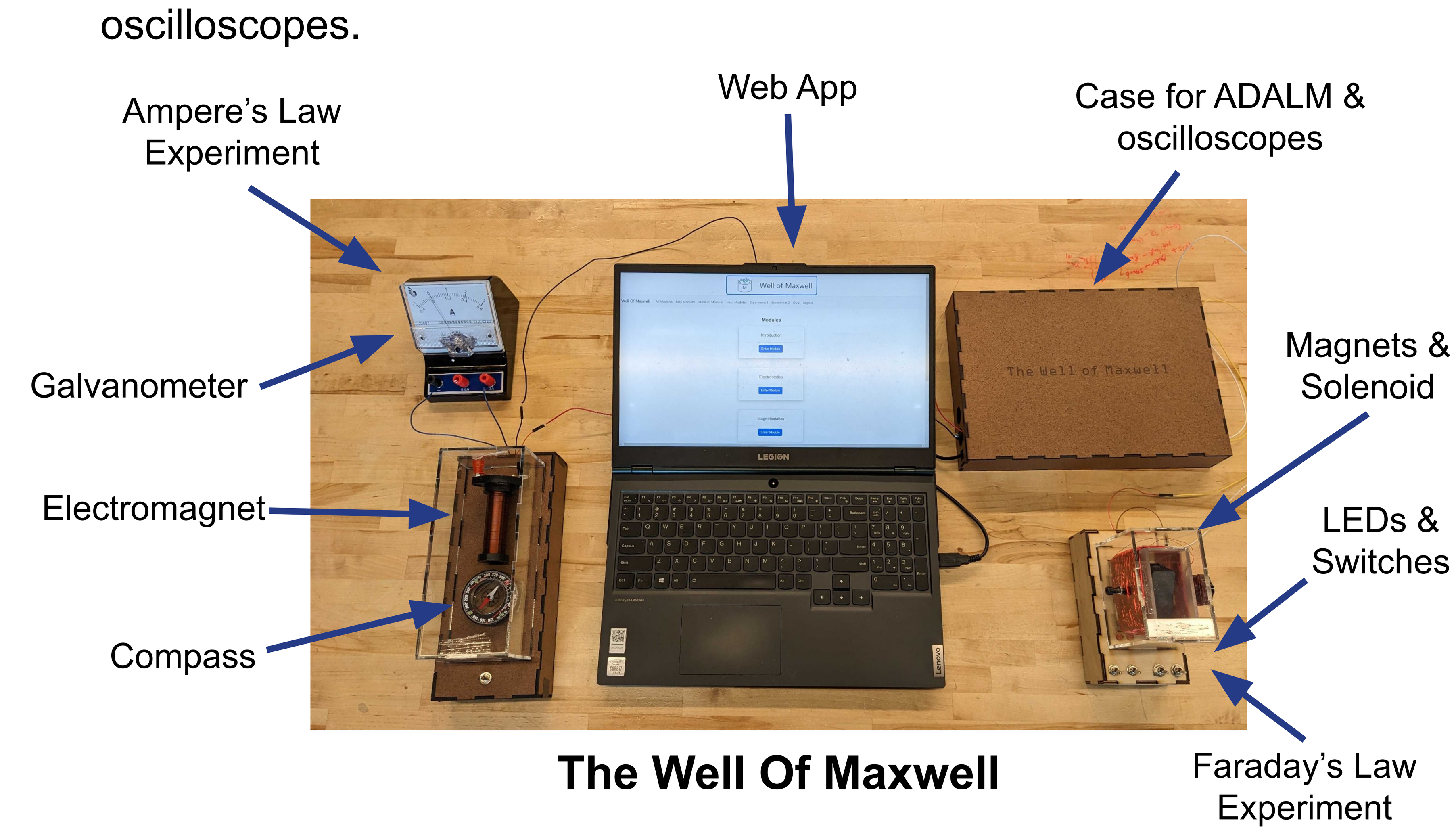
Our goal through this project is to make a science center-like booth for people of all ages to learn the importance and concepts of electromagnetism. We believe users can have fun interacting with the experiments while also diving into the fascinating field of E&M through the web app. Through this project, we learned not only the engineering process that transforms an idea into a product, but also the various ethical and social considerations that affect engineering decisions. In the future, the circuits can be made more robust and the integration more seamless. Eventually, we hope this project can be used in classes involving E&M as an interactive supplementary teaching tool.

http://course.ece.cmu.edu/~ece500/projects/s23-teamd6/

System Description

The system can be split into three components:

1. **Faraday's Law Experiment**: User rotates two magnets placed inside a coil of magnet wire to induce a voltage in the coil, which is measured by an oscilloscope and powers different LEDs depending on the positions of the switches.
2. **Ampere's Law Experiment**: User flips a switch between two oppositely-oriented batteries that power an electromagnet, which deflects a compass placed nearby to show the creation of a magnetic field. A galvanometer measures the direction and strength of the current powering the electromagnet.
3. **Web Application**: Operating on a Django MVC system, the web app hosts educational modules for E&M content across 3 difficulty levels, and displays data from the experiments that it receives via the integrated ADALM oscilloscopes. A Python data processing script utilizes the libm2k and SciPy libraries to collect and filter voltage readings from the oscilloscopes.



The Well Of Maxwell

System Evaluation

Our quantitative requirements for the design were to have visual indications of physical phenomena, accurate measurements, low latency and high repeatability of experiments, which we tested as detailed below:

Specification	Test	Passing criteria	Performance
Visual indication of the induced EMF	Measured the induced EMF with an oscilloscope	The induced voltage is higher than the turn-on voltage (V_{on}) of a red LED (**~1.8 V**)	Achieved a peak-to-peak voltage of **4.54 V** at **6.65 Hz**
	Connected the solenoid to a red and a blue LED separately and spinned the magnets	The induced EMF is sufficient to turn on LEDs	Both the red and the blue (**V_{on}=~3.4 V**) LEDs were turned on
Visual indication of the magnetic field	Observed the deflection of the compass' needle in the presence of an induced magnetic field	**> 90°** deflection	The needle is deflected by **> 120°** for both current directions
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 second**	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

* We decided to use an ADALM as our oscilloscope to measure voltage data instead of an Arduino for the former's better resolution, higher accuracy, and lower latency.

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