Jupyter-based Physics Labs:
Introducing Scientific Computing & Discovery

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Motivation

1. There is a growing body of evidence that physics labs designed to reinforce classroom instruction are less effective than labs that aim to teach experimental practices [1, 2]. Furthermore, structured labs have been shown to deprive students from actively engaging in the majority of the cognitive tasks that practicing experimental physicists routinely encounter [1].
2. Physics reviewed its undergraduate programs in W2020. One clear outcome was that all science students require some minimal competency in scientific computing. This conclusion came as a result of consultation with the physics faculty and staff, surveys of recent graduates, and evaluation other Canadian physics programs.

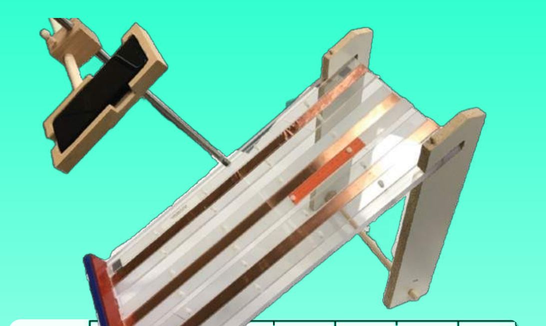
Top Left: In Lab 8, when a strong magnet is slid down a conducting track, it experiences a braking force due to the induced Eddy currents.

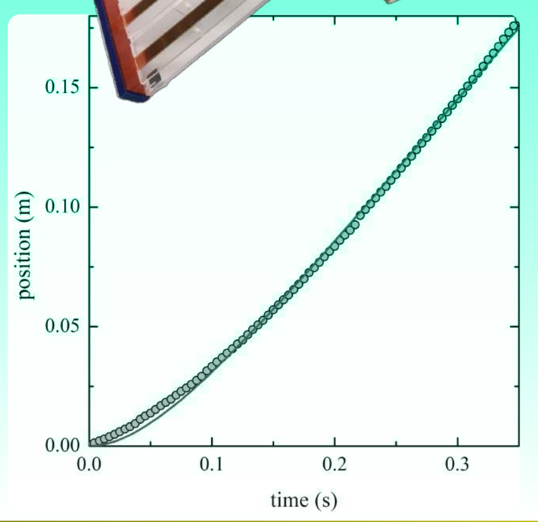
Bottom Left: Students test models designed for the cases of:

1. zero braking
2. weak braking
3. moderate braking
4. strong braking

The plot shows weak-braking data. The magnet reaches terminal velocity after a brief period of acceleration.

Right: An array of copper coils and LEDs are used to show the counter-flowing Eddy currents that precede and follow the sliding magnet.





Objectives

1. Create activities that give students more authentic lab experiences by allowing them to discover new knowledge rather than confirming concepts from lecture.
2. Give students a soft introduction to scientific computing using Python & Jupyter notebooks. Achieve this goal without requiring complex syntax or coding skills.

Example "Discoveries"

- **Labs 1 & 2:** A pendulum's period depends on it's oscillation amplitude.
- **Labs 4 & 5:** While electrical resistance is $\propto A^{-1}$, the resistance to fluid flow through a pipe is $\propto A^{-2}$ [3].
- **Lab 7:** At our geographical position, Earth's magnetic field is nearly vertical [4].
- **Lab 8:** Students are introduced to magnetic braking, an application of Faraday's law that we don't explicitly cover in lecture [5].

Interactive Jupyter Notebooks

The Jupyter notebook-based lab manuals have a number of unique advantages which include:

- Access to powerful pre-built Python packages such as NumPy, Pandas, Matplotlib, SciPy, & SymPy.
- When used with UBC's Jupyter Open, there's no cost to students and no software to install.
- Allows novice users to execute code line-by-line or block-by-block.
- Detailed notes and instructions can be interspersed between lines of code using Markdown. Can include figures, gifs, videos, and links to useful resources.
- Instructors can provide pre-written functions that students can use when analyzing their data and presenting their results.
- Ability to incorporate auto-grading which provides students with instant feedback as they are completing the labs and pre-lab assignments.
- Allows TAs to focus on providing more detailed and formative feedback related to the learning objectives.
- When needed, sets of simulated data can be generated with each student getting a unique dataset.
- Lab work is submitted electronically and feedback is provided electronically.
- Students access the lab manuals and pre-lab assignments simply by clicking a link in Canvas.

Context

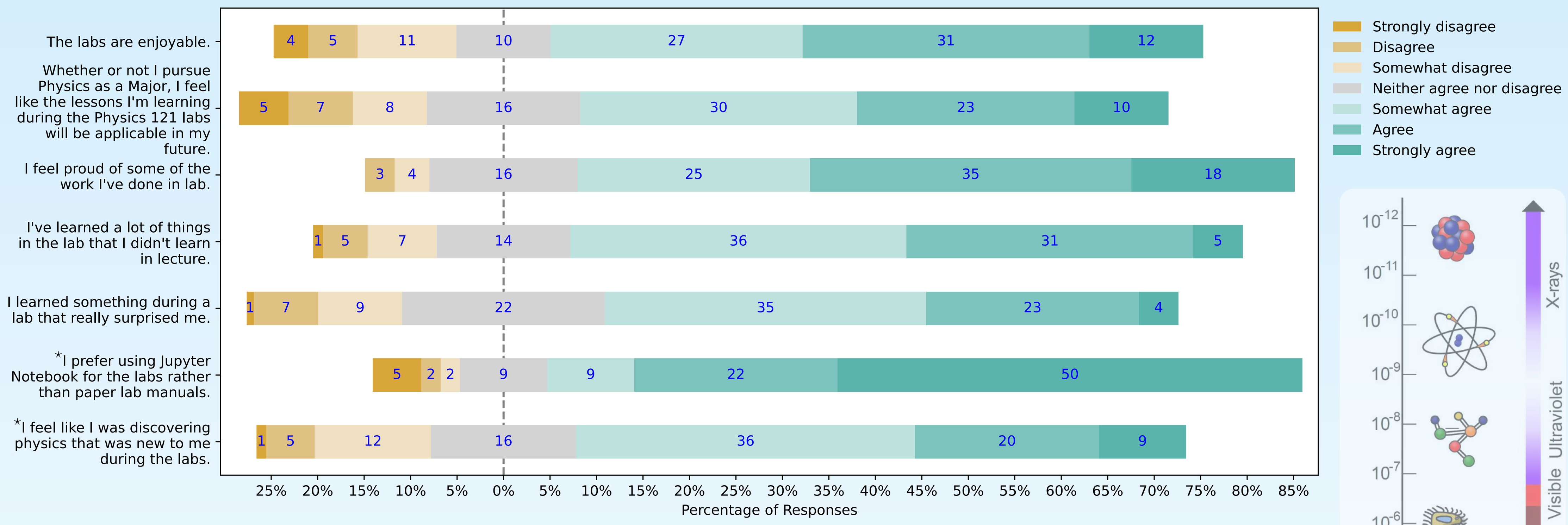
The Jupyter notebook-based labs have been implemented in our W2022 & W2023 offerings of PHYS 121. This is a term-2 course in electricity & magnetism intended for students planning to pursue a degree in the physical sciences and typically has approximately 150 students and 10 lab sections. The labs are run by a mixture of undergraduate and graduate TAs.

To assess the effectiveness of the new labs, we collected data from multiple data sources in both W2022 and W2023:

- Midterm and end-of-term surveys of all students.
- Mini-surveys of TAs after each lab.
- End-of-term surveys of TAs.
- Open feedback from students available at the end of each lab and pre-lab.
- End-of-term semi-structured interviews [6].
- A complete log of responses entered by each student in each lab and pre-lab.

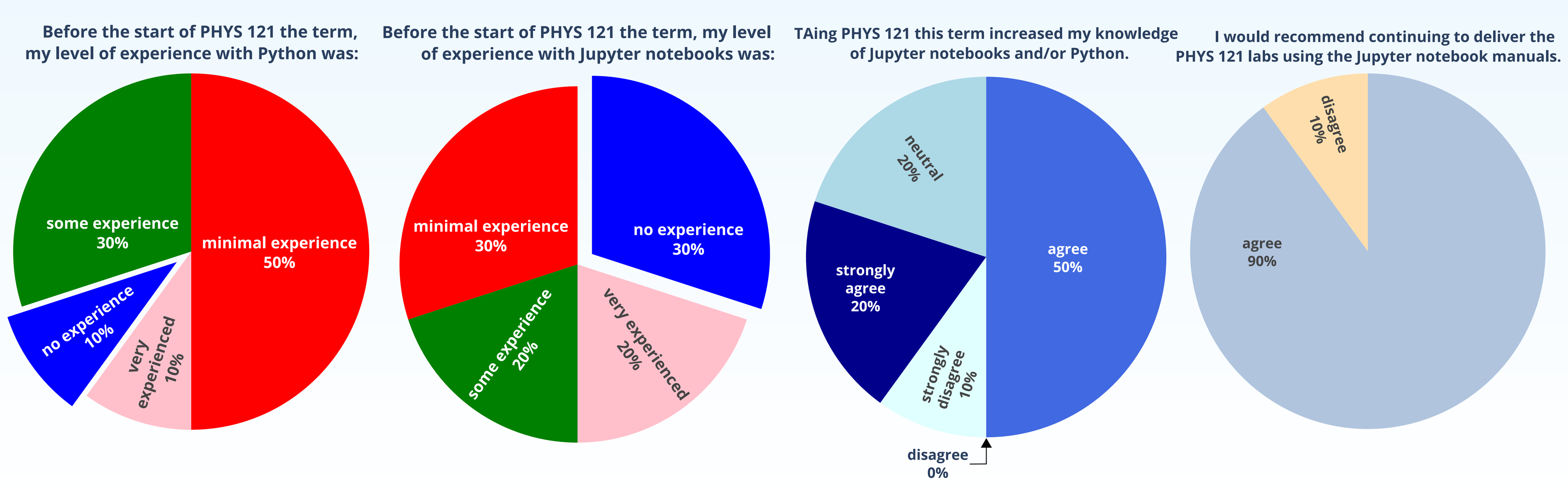
End-of-Term Student Surveys

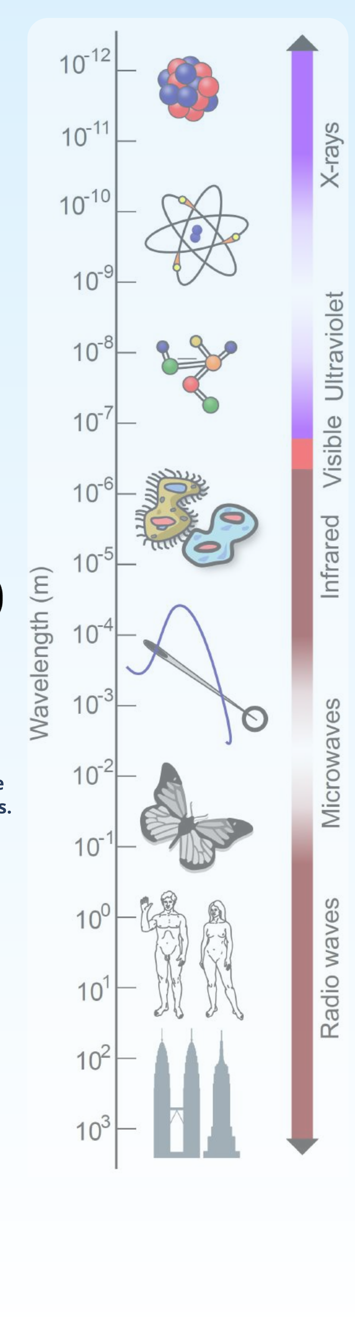
The figure below shows the combined student responses to several questions taken from the W2022 and W2023 end-of-term surveys. The blue numbers in each bar correspond to the percentage of respondents that selected that option. For the first 5 questions, there were $N = 188$ responses collected. Because they were only included in the W2023 survey, there were $N = 96$ responses for the last two questions marked by a ⋆.



End-of-Term TA Surveys

Combined results from W2022 & W2023 TA surveys. There were $N = 10$ responses. (Some TAs ran multiple lab sections.)

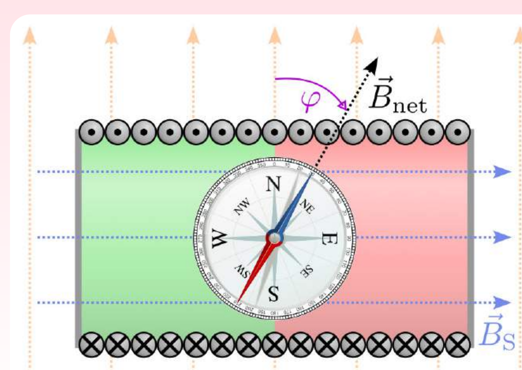


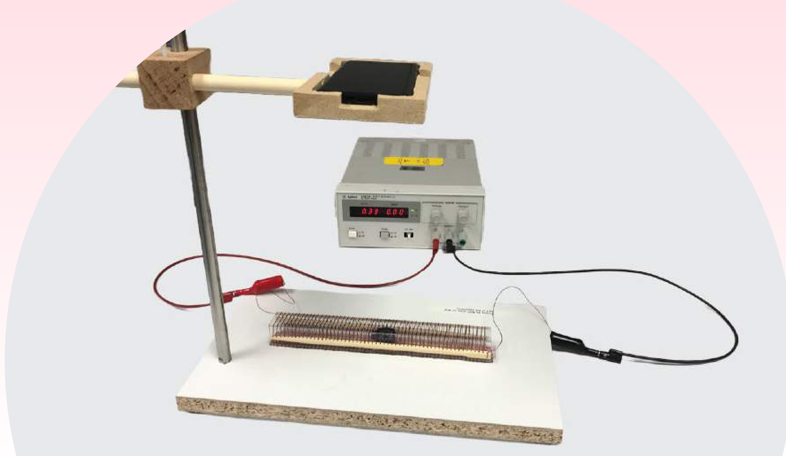


Semi-Structured Interviews

Each of the W2022 interview transcripts were independently coded by 4 different researchers. The most common themes to emerge from the interviews included:

- The Jupyter notebook-based lab manuals were liked.
- Data collection was tedious.
- Acquired new skills and learned concepts not covered in the lecture.
- Some technical issues were encountered.
- The pre-labs were helpful.





Open Feedback

Student comments from the open feedback that reflect some of the same themes extracted from the interview data:

- Prelab 1: "Being able to generate graphs this easily is very convenient. Although there's a learning curve to this software, I think it will work very well for our labs."
- Lab 1: "Great lab, crazy amount of trials but it was interesting to see the affect it had on the experiment."
- Lab 2: "I like that this lab develops and expands upon the previous lab and your results, encouraging more critical and scientific thinking."
- Lab 4: "This lab was dope. We are stoked about learning the interface as well as cool physics concepts. cheers homie."
- Lab 5: "Good lab! This lab gave me some good insights for how a capacitor charges and discharges..."
- End of term: "I enjoyed how this lab was based more in actually thinking about what is happening in the lab and why instead of all the lab time being taken up by calculations."

[1] Holmes et al., Phys. Rev. Phys. Educ. Res. **13**, 010129 (2017).
[2] Holmes and Wieman, Phys. Today **71**, 38 (2018).
[3] Bobowski, Phys. Teach. **59**, 560 (2021).
[4] Stewart, Phys. Teach. **38**, 113 (2000).
[5] Molina-Bolívar and Abella-Palacios, Eur. J. Phys. **33**, 697 (2012).
[6] Galleta, *Mastering the Semi-Structured Interview and Beyond.* New York University Press, 2013.

https://github.com/UBC-Okanagan-Physics-Labs
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UBC Okanagan
ALT-2040 Showcase
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