Jupyter-based Physics Labs:
Introducing Scientific Computing & Discovery

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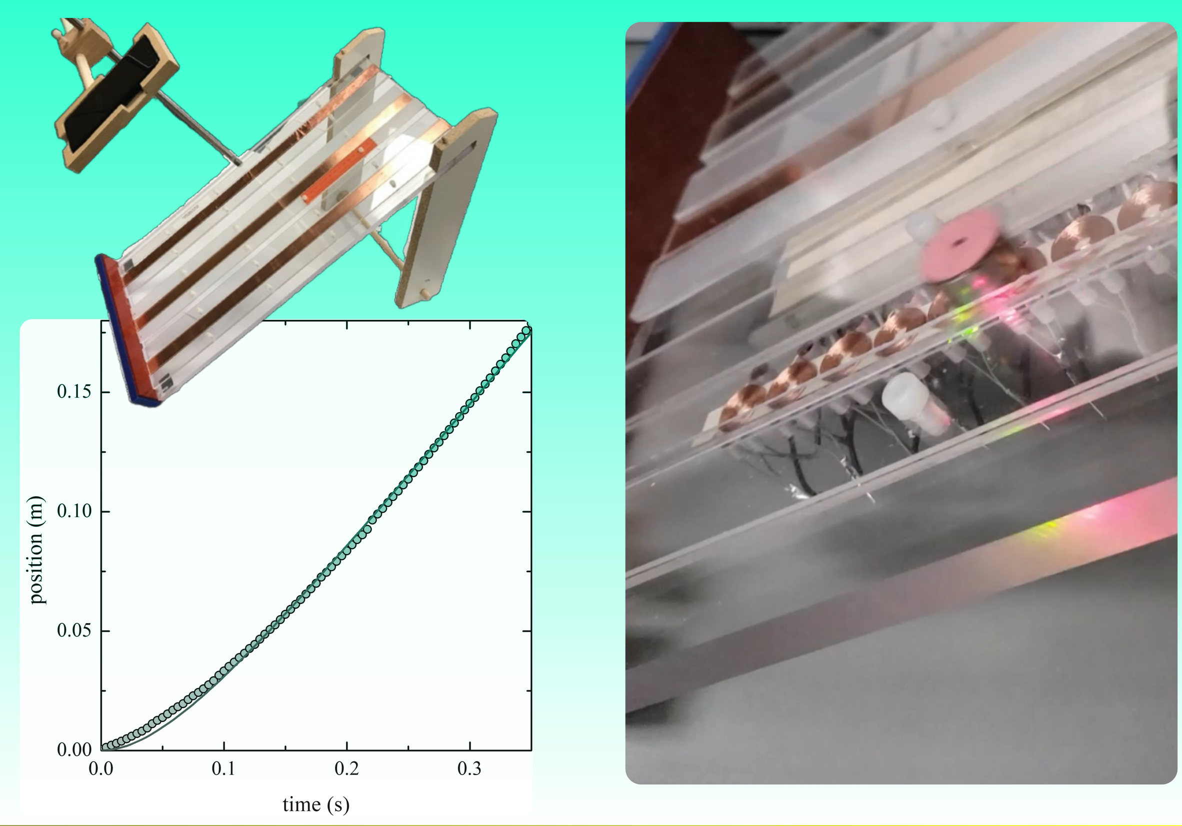
Motivation

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 to correspond to the cases of (i) zero braking, (ii) weak braking, (iii) moderate braking, and (iv) strong braking. The plot shows the weak-braking case. The sliding magnet reaches terminal velocity after a brief period of acceleration.

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



Objectives

1. Create activities that give students a 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:** A moving magnet produces Eddy currents in conductors that tend to oppose the magnet's motion.

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

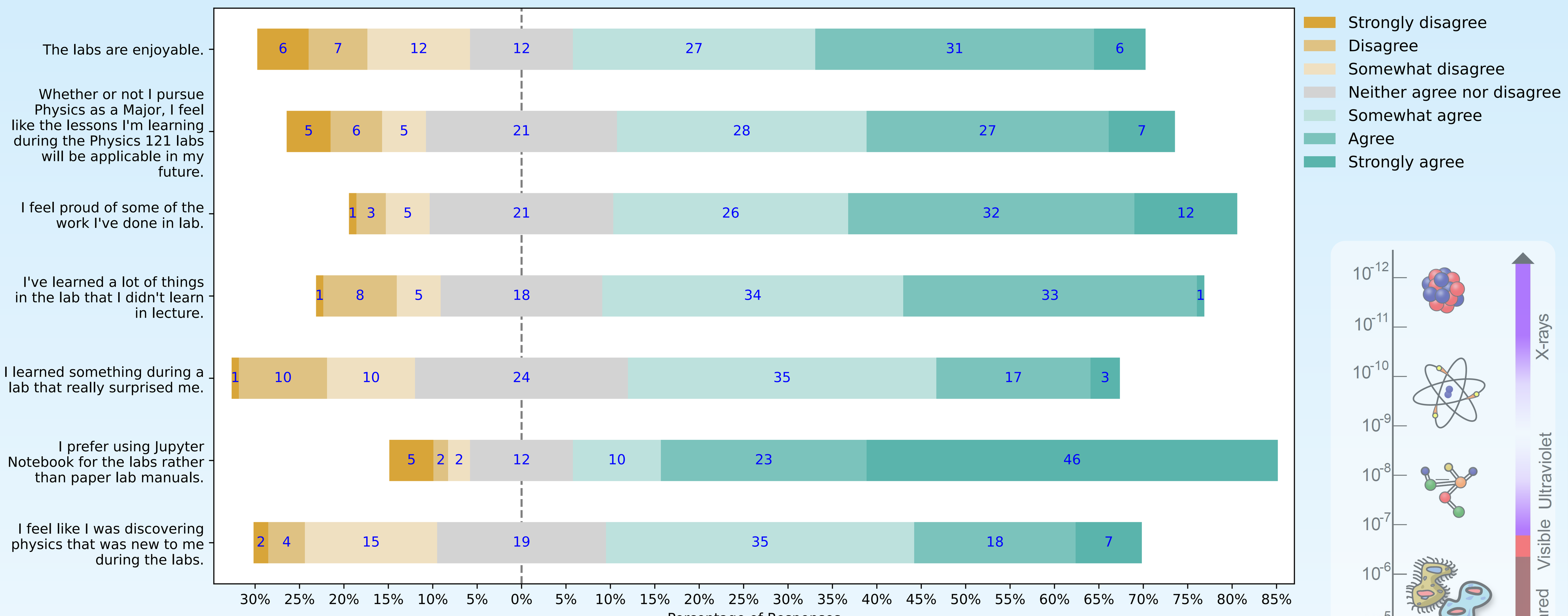
The Jupyter notebook-based labs have been implemented in our W2022 & W2023 offerings of PHYS 121. This is a term-2 course in electricity & magnetism intended for students planning to pursue a degree in the physical sciences and typically has approximately 150 students and 10 lab sections. The labs are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

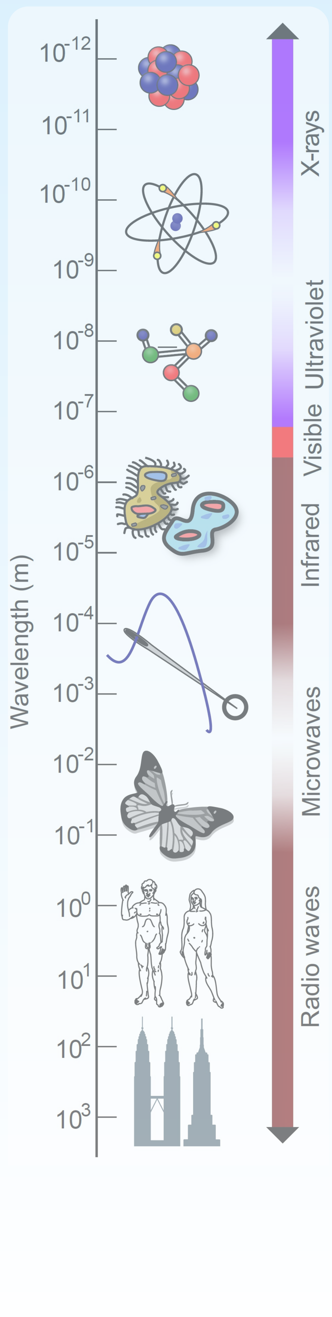
To assess the effectiveness of the new labs, we collected data from multiple data sources in both W2022 and W2023:

- 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 [5].
- A complete log of responses entered by each student in each lab and pre-lab.

End-of-Term Student Surveys

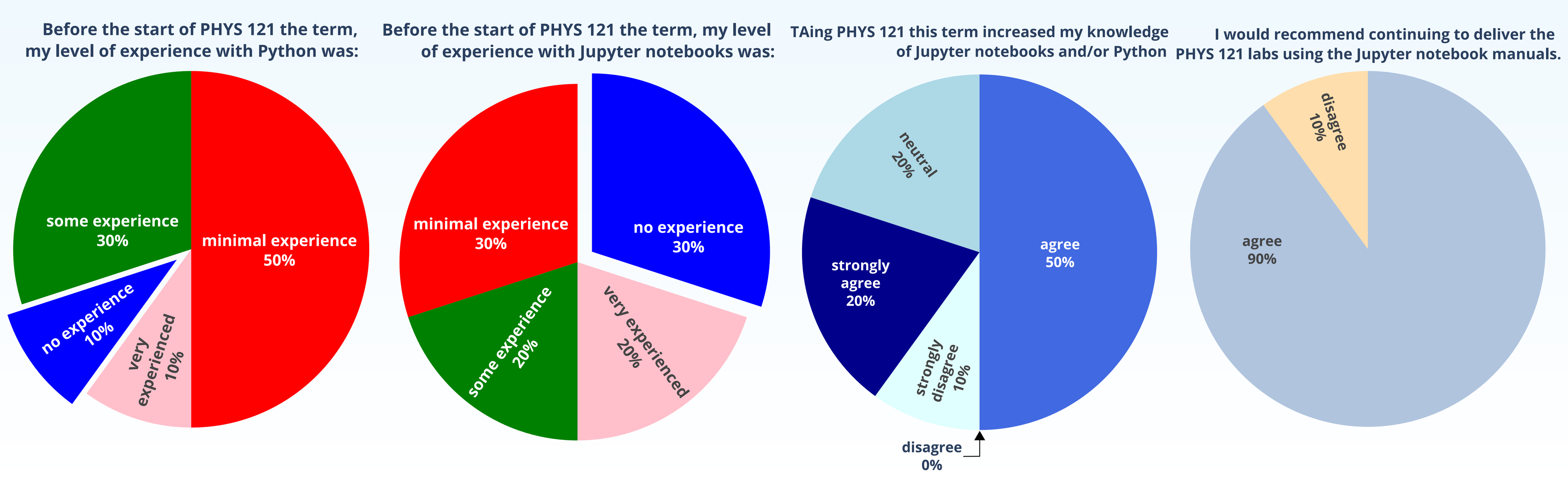
The figure below shows the combined student responses to several questions taken from the W2022 and W2203 end-of-term surveys. The blue numbers in each bar correspond to the percentage of respondents that selected that option. There were approximately $N \approx 240$ responses collected. Because they were only included in the W2023 survey, there were $N \approx 120$ responses for the last two questions.





End-of-Term TA Surveys

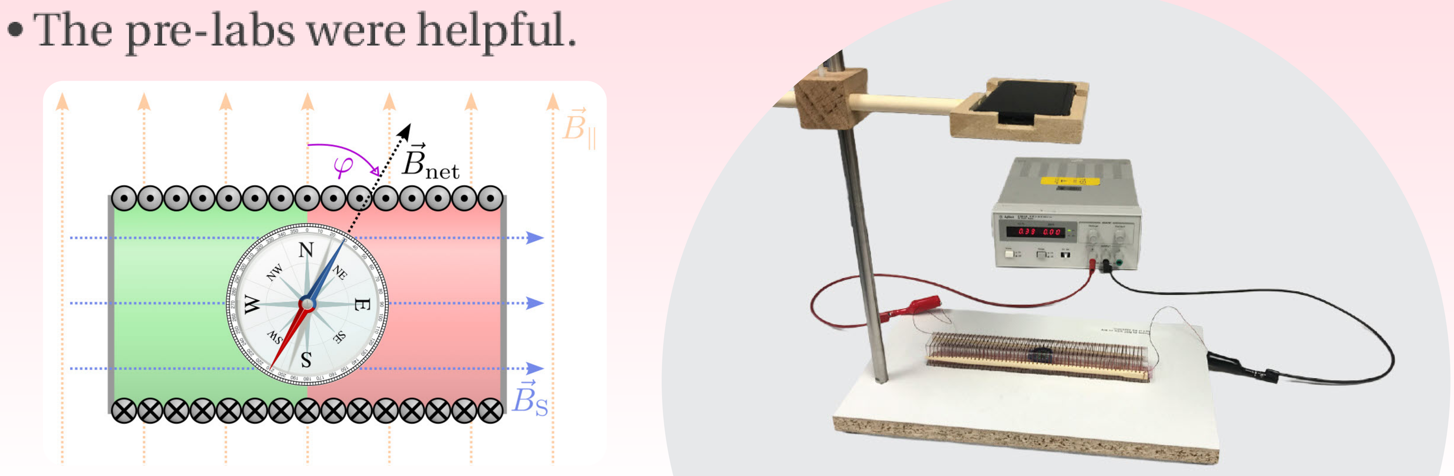
Combined results from W2022 & W2023 TA surveys. There were $N = 10$ responses. (Some TAs ran multiple lab sections.)



Semi-Structure 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 1: "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] Galleta, *Mastering the Semi-Structured Interview and Beyond.* New York University Press, 2013.

https://github.com/UBC-Okanagan-Physics-Labs
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