Use of Jupyter Notebooks to increase coding across the curriculum.

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Abstract

The engineering physics program at The University of Central Arkansas includes an electronics course for 2nd-year students. This course uses a project-based curriculum. Students complete ten directed laboratory projects and a final comprehensive project at the end of the semester. Students must maintain laboratory manuals for each activity. The program requires the use of the Python scripting language throughout upper division coursework. The department is changing its curriculum to introduce coding in the 1st-year physics sequence. To reinforce these skills, the electronics course will introduce the use of Jupyter Notebooks (JN) as the laboratory notebook format. A JN is a web-based platform that allows students to create cells of code or text. Text cells provide a platform for students to describe the "what, why, and how" of their measurements. Code cells can run Python (or many other programming languages) code. This allows students to use Python code to complete initial analysis of data and to perform calculations related to the implementation of the activity. This paper will discuss several issues associated with the use of JN as the laboratory notebook. Student preparation prior to the class and their mastery at the end will be discussed along with the implementation of this approach. This is a work in progress.

Introduction

Students in the Engineering Physics program at the University of Central Arkansas are required to take an electronics course during their 2nd year. During the spring semester of 2022 students were introduced to the use of Jupyter Notebooks (JN) as a tool for automating data collection and analysis [1]. A JN is a web-based platform that allows for the efficient creation of documents that include text and code [2]. The default kernel used for computation in a JN is IPython [3]. However, there are many other kernels available [4] that can evaluate code written for other computation platforms such as Octave, MATLAB, Maxima, and Wolfram to name a few.

JN's have been used in this limited format for the last two years. Their use was introduced in the third lab after students had generated their first set of frequency response data by hand. These JN's were built to use USB control of function generators and oscilloscopes to automate the generation of this data. They were not used as the lab notebook in these courses, only as a platform to automate data acquisition. In the current semester, spring 2024, they are being used as the platform for the lab notebooks.

One of the motivations for introducing these notebooks was to introduce Python coding earlier in the program. The Engineering Physics program is focused on robotics and automation. The two 3rd year robotics classes rely heavily on students coding in Python. Using the JN in the electronics course introduced this skill earlier. The drawback to introducing them only for automation is the complexity of the code required for this use. If students are not already familiar with Python, this can be overwhelming. This has led to the idea of using JN's as the standard lab notebook for the entire semester.

The use of JN in the classroom is growing [5] [6] [7]. The University of Washington has created a server to allow faculty to use JN's without the need to install software on individual machines [8]. With their wide use in industry and research, it is important that we adopt there use in the classroom as well.

The Class

The class is ENGR 2447 Electronics. Prerequisites for the course are the second semester of a 1st year physics sequence covering electricity and magnetism and a semester of calculus. The course covers the first six chapters of the textbook written by Curtis Meyer [9]. This takes the students through RC and RL filters and basic diode and transistor circuits up to operational amplifiers. The class does not use a traditional lecture lab format. Enrollments are small enough that classes are taught in the lab room over the equivalent of two lab periods. Lectures, student presentations, and laboratory activities are comingled throughout the scheduled meeting times.

Student in this class will have taken the second semester of the 1st-year physics course sequence which covers basic circuits. They will complete 10 lab activities leading up to a seminal design project at the end of the semester. The lab activities are adapted from the lab manual that accompanies the textbook. The labs have been edited to use JN's as the lab notebook format along with the equipment available in the labs at the University of Central Arkansas. Two years ago, the author added a new laboratory [1] that featured code to automate the acquisition and analysis of data. This code used JN's as a frontend. Students were required to complete minor alterations to the code to complete each measurement. It was noted that the use of experiment control files is a one way of maintaining records of measurements.

In the three terms the author has taught this course, the students have demonstrated various levels of coding proficiency at the start of the semester. During the first semester the class was very comfortable with coding and had experience working in Python. During the second the students were very new to coding with very little experience using Python. By the end of the term, they were actively adapting the code to the different measurements involved in the lab activities. Students in the current term display the same breadth of experience as in the first two classes.

This course is an opportunity to develop not only the knowledge of electronics, but also coding skills through specific activities associated with the labs. During the spring 2024 semester students will be required to use the JN format as their lab notebook. They will have the option of completing lab reports in this format but will not be required to.

First Notebook Lab 00

The meeting format for this course provides 2 3-hour classes each week. This normally would have allowed for a lengthy introduction to JN's during the initial class period. Unfortunately, the weather at the beginning of the semester prevented this. One of the advantages of the JN is that it is a web-based platform. This allowed for an easy transition to an asynchronous instruction format for the first day of class. During the first class, students were introduced to the notebook using an example book. The "Lab 00 Notebook Template" [10] contains examples of the formatting available in a JN.

Lab 00 is designed to introduce students to some of the capabilities of the JN. The initial cells in this notebook are Markdown text cells. They illustrate the use of these types of cells in a lab notebook or report setting. The cells illustrate the procedure for including:

1. Headers
2. Bold and or italics text
3. Numbered or Bulleted lists
4. Tables of data
5. Equations developed in LaTeX script
6. Web links
7. Importing Images.

These examples will allow students to include equations, data tables, images of circuits, and any other information that would normally be included in a lab notebook.

The last two cells of the notebook introduce some simple Python code. Each of the cells is heavily commented to explain what the code does. The first of these cells introduces the *numpy* package, creates an array of numbers, and uses those numbers in a *sin()* function. This cell also discusses the fact that Python enumerates lists and arrays starting with '0' and not '1.' The end of this cell gives a very brief introduction to outputting formatted numbers.

The second cell introduces the *matplotlib.pyplot* package. This package can be used to produce graphs of data and calculations. The cell uses the data from the calculations in the previous cell to create four plots with different line styles. Using the data from the previous cell illustrates an important aspect of a JN, the results of previously run cells are available to cells being run later. This can also be a trap, as cells can be run out of order causing unwanted results.

The lab activity that accompanies this JN is "Lab 00.pdf" [11]. It not only introduces students to the JN platform but to the Linux operating system as well. While JN's run under any operating system (it is more difficult on Chromebooks), we provide classroom laptops with Ubuntu 22.04 installed. This serves to introduce the students to the operating system they will use in the Robotics 1 and 2 courses later.

Lab 01 Notebook

The first lab that pertains to electronic components deals with DC circuits, *I-V* curves, and developing the idea of the equivalent circuit (thévenin circuits). The lab activity [12] takes students through the process of measuring the relationship between current and voltage for a number of components. Students can download a JN, "Lab 01 Notebook Template" [13], to accompany the lab handout.

This template provides a platform that students can use to record and display the data for this activity. The template starts out importing both *numby* and *matplotlib.pyplot* for use in later cells. It then moves into the pre-lab questions for Lab 01. Each lab will require the students to have completed pre-lab questions before they come to class. The answers for these questions can be analytical, code based, or imported figures. The last cell provides a brief introduction to one method of curve fitting.

Following the pre-lab questions, the template includes a brief review on how to record data in table in a markdown cell. What follows is an example data acquisition in a format that uses Python code to display the data. *I-V* curves are created. A quick example of a markdown cell introducing a measurement is given. The process for editing these cells is discussed in class. It is noted that students should include circuit diagrams as well as actual values for electronic components in their descriptions.

Lab 03 Notebook

The third lab activity introduces the students to the use of the computer to automate their data collection [14]. This is the most involved template of the semester. This JN [15] automates the collection of frequency response data that was done by hand during Lab 02. During class, I will demonstrate how this JN works. We will collect one set of data as an example. I then show students how they can collect the next set of data without having to retype the code. Cells can be easily copied to repeat measurements using different parameters.

This was discussed extensively in [1]. While in previous semesters, the JN was introduced only as the platform for automating data acquisition. This semester, it has been introduced as the platform for lab notebooks. The fact that the notebook (especially those automating data collection) can provide a solid record of the steps taken in data acquisition and analysis is stressed in class. Students are encouraged to be conscience of overwriting measurements that do not go as planned.

Later Notebooks

Later notebook templates will introduce new capabilities as needed. The fourth lab, "Lab 04.pdf" [16], introduces the temporal response of RC and RL circuits to an impulse signal. Students will need to download data from the oscilloscope to the computer for analysis. The notebook template [17] contains code that is designed to generate the downloads. It will be demonstrated in class and students will need to modify this code for their specific measurements.

Unless new capabilities are needed, only the pre-lab questions will be included in notebook templates. The template for the fifth lab is an example of this [18]. Students are expected to include the appropriate packages for any measurements and analysis they will need to perform. As an example, the fifth lab [19] introduces *RC* and *RL* filters. Data is collected to determine the frequency response of these types of circuits. It is displayed in the form of Bode plots. All these techniques have been introduced in earlier labs. Students will need to include the script necessary to complete these measurements in this notebook.

Further Work

Student response to the notebooks used this semester will guide further development. It is possible to use this format to produce reports as well as raw notebooks [20] [21]. There are some reasons to do this. Students can create static versions of their notebooks that are more readable. The static nature of the report serves the purpose of being a static record of lab activities. Whether or not to move to using the JupyterLab format is also an open question.

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