

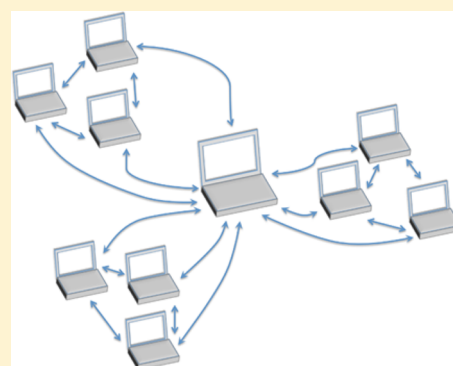
Working toward a Paperless Undergraduate Physical Chemistry Teaching Laboratory

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S Supporting Information

ABSTRACT: The use of electronic formats for obtaining, recording, analyzing, and disseminating data is becoming ubiquitous in classrooms, teaching laboratories, research laboratories, and industry. The undergraduate physical chemistry teaching laboratory provides an excellent opportunity to ensure that upper-division chemistry students gain experience in using electronic means of recording and presenting the results of their experiments. To facilitate this action, computers are used in as many aspects of the course as possible: obtaining introductory material, preparing pre-lab reports, recording data in a simulated electronic lab notebook, and submitting final lab reports. Since the physical chemistry laboratory is an advanced undergraduate course, the students are also given increased responsibility for the experiment, creating their own procedure from papers, textbooks, and other additional information.



KEYWORDS: Upper-Division Undergraduate, Laboratory Instruction, Physical Chemistry, Computer-Based Learning, Hands-On Learning/Manipulatives, Laboratory Computing/Interfacing

In the undergraduate chemistry curriculum at most institutes of higher learning, all chemistry majors must take at least one semester of physical chemistry including lab. These students are almost always juniors or seniors and have the maturity and experience to undertake increasingly independent and sophisticated actions. Therefore, the undergraduate physical chemistry teaching laboratory provides an excellent opportunity to ensure that all undergraduate chemistry majors obtain experience using electronic methods of gathering and dispersing information. This paper describes the implementation and ongoing use of freely available online applications and commonly used word processing software for data collection, storage and reporting in an undergraduate physical chemistry teaching laboratory course. In this class, students create documents and share information using Google Drive,¹ the Google Docs app accessed from within the Google Drive folders, and Microsoft Word.² The portability of the Google applications allows them to be used by students with varied types of devices and allows the students to access their work and information from anywhere they can access the Internet. Using Google Drive as a platform allows for version control, creation of a shared space, and most importantly, real-time and simultaneous interactions between students and the instructor.

There are many advantages and disadvantages for the use of computers and online applications in the classroom³ and the use of electronic methods to enhance chemical education has been explored by several others.^{4–6} Often, the online capabilities of such tools are used to allow for collaboration and sharing of data between all of the students in the class and to take advantage of the functionality of electronic applications.^{7–9} For example, in a 2012 *Journal of Chemical Education* paper, Neil Abrams¹⁰

outlined the use of cloud networks and course management systems for sharing data among students. In a news feature in *Nature*, David Butler weighed the pros and cons of electronic notebooks finding mostly advantages, but also noting the reluctance of some groups to adopt an electronic notebook format.¹¹ Benedict et al. have also explored how Google Docs can be utilized to create a rip-mix-learn classroom allowing students to create sets of collaborative lecture notes.¹² Recently, Amick and Cross¹³ have shown how electronic methods can be used effectively in the lab and classroom, having reported using iPads, Notability,¹⁴ email, iCloud,¹⁵ Dropbox,¹⁶ or Google Drive to achieve an almost paperless organic chemistry lab where the experimental procedures, lecture notes, student data, and student reports are electronic.

■ THE PHYSICAL CHEMISTRY LAB

The students meet in the laboratory once a week and each experiment consists of a minimum of two, 3 h laboratory periods. The students must typically work in groups, and due to limited numbers of instruments, not all groups can perform the same experiment at the same time. The instructor must monitor the different groups, each group using different methods, and try to ensure they all remain on the right track. Using the applications in Google Drive to write the pre-lab report, experimental procedure, and to simulate an electronic notebook during the experiment helps to ease or eliminate some of the issues arising

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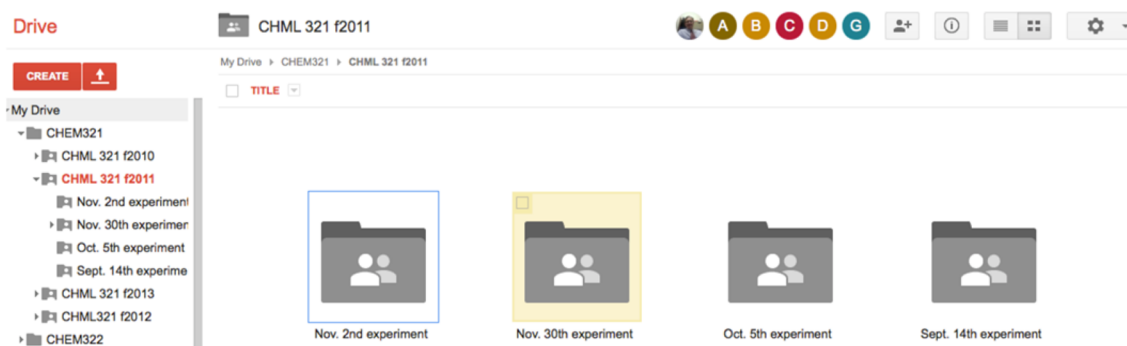


Figure 1. Example of the folders set up for the physical chemistry teaching laboratory.

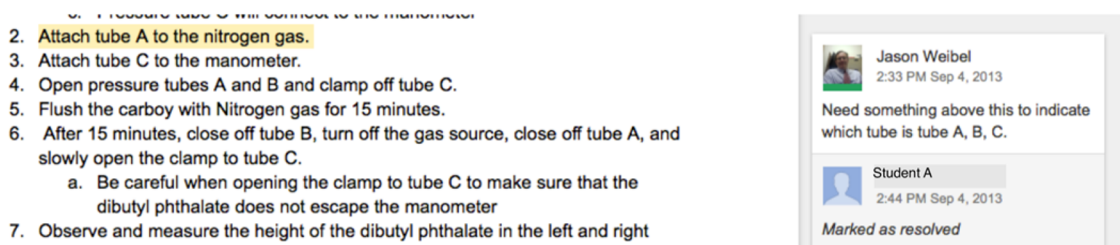


Figure 2. Example of the interaction between instructor and the students in the preparation of the pre-lab report in a Google doc.

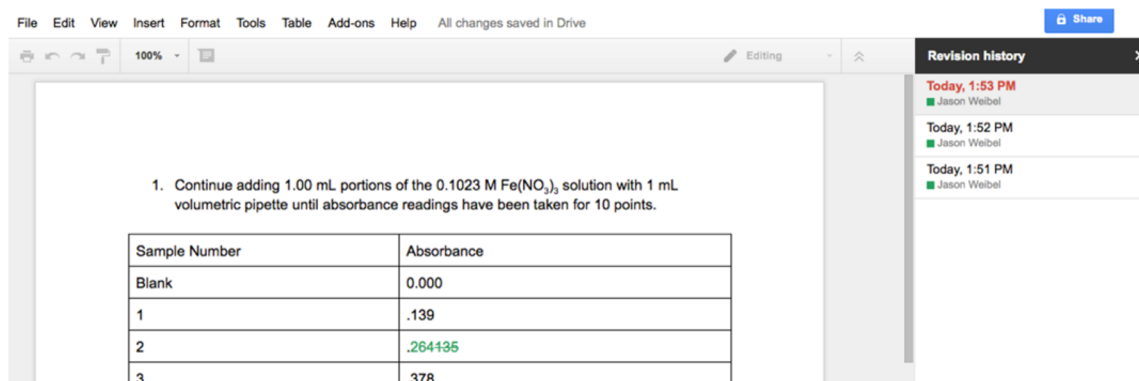


Figure 3. Example of a laboratory notebook for the course, with a record of revisions.

from this complexity. Conducting these aspects of the course online allows the instructor to easily observe multiple groups simultaneously from their computer and make comments while the students are creating the documents.

Pre-Lab

Prior to the first lab period, folders are set up by the instructor on Google Drive and shared with the students in the course, see Figure 1 for an example.

During the first period, the students are presented with papers, textbooks, and additional information describing the experiment. It is here where the last nonelectronic aspects of the course, besides the experiments themselves, remain, as some of the information comes from textbooks or papers that have not yet been digitized. From this information, under the instructor's supervision, the students must write a pre-lab report including a purpose for the experiment, a materials list, and an experimental procedure. Figure 2 is an example of the type of interaction that takes place while preparing the pre-lab report.

If the students are unfamiliar with the experiment and/or equipment, they may spend the remainder of the period gaining familiarity. All of the pre-lab information must be completed and

approved by the instructor before the students in the group can leave that laboratory session. The pre-lab format that the instructor presents to the students with the course syllabus is available in the Supporting Information for this paper.

Laboratory Experiment

The experiment itself is performed during the second day of the two lab period sequence. Before the start of the course, the instructor sets up folders on Google Drive for each of the students that serve as the student's simulated electronic lab notebook. Prior to lab, each student creates an outline of the experiment in their simulated electronic notebook using a copy of the approved pre-lab document adding tables for recording data. Again, the use of Google Drive allows the instructor to check the notebooks prior to and during the experiment and to easily monitor multiple notebooks during the lab period. Creating a document on Google Drive also simulates an electronic lab notebook in that revisions to the notebook are recorded. Therefore, a student cannot go back and change information without a record of the change being made, see Figure 3 for an example.

I. By formatting the Arrhenius equation:

$$k = Ae^{(-E_a/RT)}$$

E4

into linear slope form:

$$\ln k = -(E_a/R)(1/T) + \ln A$$

E5

a graph plotting the $\ln k$ vs. $1/T$ and the activation energy (E_a) could be solved for. The slope of the line of best fit on the graph plotting $\ln k$ vs. $1/T$, was equal to $-E_a/R$.

Experimental: In this experiment, four solutions were prepared and then combined to test reaction times. The solutions prepared were a 0.1 M $(\text{NH}_4)_2\text{S}_2\text{O}_8$ solution; a 0.1 M $(\text{NH}_4)_2\text{SO}_4$ solution; a 0.01 M $\text{Na}_2\text{S}_2\text{O}_3$ solution; and a 0.1 M KI solution. These solutions were then combined in various quantities in addition to a few drops of starch to complete seven separate trials (actual volumes used listed in appendix). The reaction time was then recorded. For the second part of this experiment, the same solutions of $(\text{NH}_4)_2\text{S}_2\text{O}_8$, $\text{Na}_2\text{S}_2\text{O}_3$, and KI, previously made were used again.

before calculation of the rate constant, k.
Weibel, Jas..., 10/9/2013 11:23 PM
Comment [8]: What is the relationship seen in the Arrhenius equation?

Weibel, Jas..., 10/9/2013 11:23 PM
Comment [9]: Also used the plot to determine the value of A.

Weibel, Jas..., 10/9/2013 11:24 PM
Comment [10]: Is there someplace where the various quantities are listed?

Figure 4. Example of a graded final lab report, including comments included by the instructor.

The instructor approves the experimental work and data before the student leaves that laboratory session. An example lab notebook format that is presented to the students with the course syllabus can be found in the Supporting Information for this paper.

Post-Lab Work

After completion of the experimental portion of the lab, the students write a lab report, including introduction/background, experimental, results, discussion, reference, and possible appendix sections, using Microsoft Word and e-mail it to the instructor. The information given to the students in the syllabus on the expected format of the final lab report can be found in the Supporting Information for this paper. Using Microsoft Word, rather than Google Docs better simulates situations where once the lab report is submitted, no other changes can be made to the report. The instructor then grades the lab report using the comment feature of Microsoft Word, see Figure 4 for an example, and records the grade for each section in a table at the beginning of the document, see Table 1. for an example of the grading rubric.

Table 1. Example Grading Rubric^a for the Experiment

Section	Score Earned/Points Possible
Introduction	20/26
Experimental	9/10
Results	20/25
Discussion	8/12
References	2/2
Total on Written Report	59/75
Pre-lab	15/15
Technique	10/10
Overall grade	84/100

^aA grading table is added to the top of the graded lab report.

After grading the report, the instructor changes the report to read-only, requiring a password to make changes, and e-mails the graded report back to the student.

CONCLUSION

Using Google Drive, Google Docs, and Microsoft Word in the physical chemistry teaching laboratory provides students with vital skills for use in future endeavors. Google Drive allows for

feedback prior to and during lab and the use of a common online framework also allows the instructor to monitor multiple and different experiments essentially simultaneously. The time required by the instructor to set up the folders for the course does not add significantly to the overall setup time for the lab. Personal Google accounts have 15GB of free storage and university accounts can have unlimited storage. Online applications have been used in this course for five years and all the documents have been kept. During the last five years, there have been no issues with privacy and security. This format also allows the instructor to easily check the documents for originality. A copy of the checklist used to create and manage the course has been included in the Supporting Information.

In general, the students have responded favorably to the course format, with most issues arising from either confusion about requirements or dislike of the experiments themselves. Because using a simulated electronic lab notebook is new to most students, there is a slight learning curve while the students adjust to the new format and get used to recording data on their laptops. Once they become accustomed to it, the students have no trouble with the format and seem to prefer it. During the last five years, a total of 51 students have completed the course, with simulated electronic notebooks added during the last two years. The effectiveness of the use of electronic applications including the simulated electronic notebook has been monitored, after final grades had been assigned, by asking students to fill out a survey using Google Forms. The survey was filled out by 15 of the 20 students who completed the course with the use of simulated electronic notebooks. Compared to paper notebooks, the simulated electronic lab notebooks were preferred by 66.7% of the students. Additionally, 86.7% of the students indicated that they would rank this lab course as one of the top at the university, 86.7% believed that the format used enhanced their lab experience, and 86.7% believed that the lab increased their understanding of the subject material. Since the introduction of the simulated electronic lab notebooks in the last two years, the average grade on the lab reports has changed from 82% to 85%, the average grade on the lab final exam has changed from 70% to 80%, and the average overall grade for the lab course has changed from 83% to 85%.

■ ASSOCIATED CONTENT

📄 Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00585.

- Lab checklist (PDF, DOCX)
- Pre-lab format (PDF, DOCX)
- Laboratory notebook format (PDF, DOCX)
- Final lab report information (PDF, DOCX)
- Final course survey (PDF, DOCX)
- Results of the survey (PDF)

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Notes

The authors declare no competing financial interest.

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