Electronic Laboratory Notebooks versus Paper Laboratory Notebooks: A Comparison of Undergraduate Experimental Engineering Laboratory Submissions

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Abstract
Electronic Laboratory Notebooks (ELNs) are computer-based solutions for creating, storing, retrieving, and sharing electronic files. Such electronic records are now considered equivalent to paper-based records, when it comes to patent filing as well as other legal and technical issues. Advantages of ELNs include the ability to search electronically; electronic linkage and storage of potentially large data files (including newer types of electronic files, such as video); and increased accessibility and collaborative functions. A number of different software solutions are available, usually grouped by technical field and potential application of the work. In this paper, literature on Electronic Laboratory Notebooks is summarized, with a particular focus on applications to undergraduate laboratory work. An ELN system consisted of a learning management platform (Sakai) and typical word processing and spreadsheet-based programs has been adopted at Harvey Mudd College for use in a sophomore-level experimental engineering course. The ELN system and the experimental engineering course are described in detail. Four semesters of undergraduate student work from this experimental engineering course were examined: two semesters of student lab work submitted in the form of the usual paper laboratory notebooks (PLN), and two semesters of electronic submissions (ELN.) Examples of student work are presented, with a focus on assessment of good laboratory notebook practice. In particular, recording of raw data and presentation of test rig schematics were assessed. Although expectations were that raw data would be easier to record and store using the ELN, no major differences were seen between PLN and ELN student submissions. Some inclusions of photographic and video media were seen in ELN student work, but in general, students did not seem to be taking advantage of the electronic medium. Faculty experiences with the management and grading of the student laboratory notebooks is discussed. This includes storage and access of laboratory notebooks, as well as issues of grading and release of scores to the students. Faculty and grader access was improved when using the electronic system, but there was significant annoyance and resistance due to the idiosyncrasies and peculiarities of the learning management platform, as compared to the simplicity of paper laboratory notebooks.

Background

The Electronic Laboratory Notebook (ELN) is defined as a computer-based solution for creating, storing, retrieving, and sharing electronic files. Electronic records such as ELNs are now considered equivalent to paper-bound records, in terms of patent filing and intellectual property rights[1]. Advantages of ELNs include the ability to search electronically; electronic linkage and storage of potentially large data files (including newer types of electronic files, such as video); and increased accessibility and collaborative functions. A number of different software solutions are available, usually grouped by technical field and potential application of the work. ELNs are much more common in industry, compared to academia; ELNs are rarely used in undergraduate science and engineering education, although their use is beginning to be explored. In particular, the pharmaceutical industry has adopted ELNs[2].

Laboratory Notebook Practices: Paper versus Electronic

One of the most important pieces of information regarding good lab book practice is the timestamp. For paper laboratory notebooks (PLNs), which have been used for centuries to document scientific and engineering endeavors, the timestamp indicated a dated entry, in ink, which is never to be altered. For electronic storage of information, the timestamp is called metadata, or meta-information, and often refers to tagging a computer-based file (perhaps containing raw data, or information about experimental settings) with the time the file was modified. In industrial work, meta-information can also include the name of the author of the "entry." In addition to timestamps, a typical entry in a laboratory notebook is a sketch or schematic indicating the test set-up or rig. For PLNs, this can be a hand-sketched figure directly entered in ink onto the paper. Related to the test rig schematic are equipment lists. Good laboratory notebook practice emphasizes describing both the test set-up and the equipment used in an experiment. For PLNs, quickly sketching on paper has proven to be a simple solution. Hand-written equipment lists can be tedious to inscribe, but has been a staple of PLNs.

These two types of entries can be incorporated into an ELN. There are software solutions to capture sketches (which can be saved and either linked into an ELN, or inserted into a document as an image) but one would need the particular software and a computer with touchscreen inputs. Equipment lists could simply be typed and included in a document or saved as a file and linked into an ELN. Raw and processed data are a third type of entry common to laboratory notebooks. For PLNs, raw data was often handwritten into the notebooks, and the date of the entry was noted. Over the past few decades, it became more common to see cut-and-pasting of data which had been entered directly into a computer spreadsheet, and printed on paper so that it could be taped or glued into the PLN. Although this was likely not a best practice, it has become very common. Processed data were generally presented in the PLN by showing a sample calculation (changing the raw data into whatever useful processed information necessary for the experiment.) Typical examples include running a measured voltage through a calibration equation, converting units, or calculating non-dimensional numbers from measured quantities. Once sample calculations were presented, tables or plots of the processed data were typically entered into the PLN. Although hand-graphing of data was done in the past, and can obviously still be performed, computer-based graphing programs have become ubiquitous, and PLNs often contain printed graphs and tables that have been pasted or taped into the PLN. Obviously, direct linking/insertion of computer-generated graphs and tables is one way to implement data tables and graphs into an ELN, and most computers already include software that will produce tables and graphs.

ELNs in Undergraduate Education

The following section borrows heavily from Cardenas (2014)[3]. There are a few examples in the literature regarding ELNs in undergraduate education. Meyer et al described the use of an HTML-based laboratory notebook (design journal) in a capstone digital systems course at Purdue[4] . Assessment of the students' laboratory notebooks showed improvement when two tablet PCs were allocated per team, but the students reported that the HTML format was a hindrance to maintaining their notebooks, and indicated a preference for a commercial ELN solution. The authors noted that many of the student teams "took advantage of (and put to good use) the ability to post digital pictures of prototyping setups, provide hyperlinks to all their device datasheets, post their latest schematics and software listings for evaluation, and post video clips of their project in action (as verification of their project success criteria)."

The use of course management systems (CMS) such as Blackboard[5] for educational applications of ELNs was reported. CMS are web-based software packages with many functions designed to facilitate the delivery of on-line course content; support the electronic interaction between instructors and students; serve as a repository (a dropbox) for student work; and provide gradebook functions which allows instructors to enter grades, and students to receive the grades and instructor comments. Chat, blog, and forum functions are usually a part of a CMS. Woerner used a combination of common academic software and the Blackboard online course management system as an ELN in an advanced undergraduate Chemistry lab at Duke University[6]. The students used Microsoft Word and graphing software to 'create' their lab notebook components. Once their work was written, the students submitted their electronic files into the dropbox of Blackboard. Woerner reported that the students found typing equations to be time-consuming, and noted that pre-lab work went very well using the course management system.

Hesser and Schwartz[7] described a General Chemistry course at the University of New Haven that used iPads in classroom and labs. Blackboard Mobile was used to post the assignments, and the students used iPads to record the laboratory and course content. In particular, drawing apps were used; annotation of pdfs and photos was done; and the collected lab data was imported to the iPad for analysis. Students reported that the iPad was difficult to write with--this is consistent with the idea that iPads are good for consuming content, but not necessarily useful for creating content, or inputting larger amounts of text and data--but that their skills got better with time. Another concern from the students was the inability to look at more than one page of data at a time, especially when needing to compare sets of data. The authors noted that the iPad was inexpensive compared to a laptop-based solution and believed that the practice using digital-based solutions was an advantage for the students.

Commercial ELN Solutions

There are many commercial ELN solutions available. The Scientist[8] presents a good summary, including cost figures from 2010 (costs can range from $0 to tens of thousands of dollars with the higher cost figures representing ELN solutions specific to the pharmaceutical industry.) In this section we will focus on two commercial ELNs which may be appropriate for use in an undergraduate education environment.

iLabber[9] is an ELN which allows a user to create an electronic document of an experiment, including timestamping, locking, and digital signature functions. Users can input text, images, pdfs, excel files, etc. A particularly interesting feature that could be useful for undergraduate education is the option for using templates, rather than opening a 'blank' experiment. These templates could include placeholders for sections such as experimental set-up, equipment lists, and so on. Although we hope as educators that we don't always need to give the students a recipe book, perhaps in frosh laboratory courses, or in early labs in more-advanced courses, one could use the template as a way to remind the students of best laboratory notebook practices. Figure 1 shows a screenshot of iLabber. The toolbar on the left-hand side indicates the types of files that can be added to the electronic experiment document.

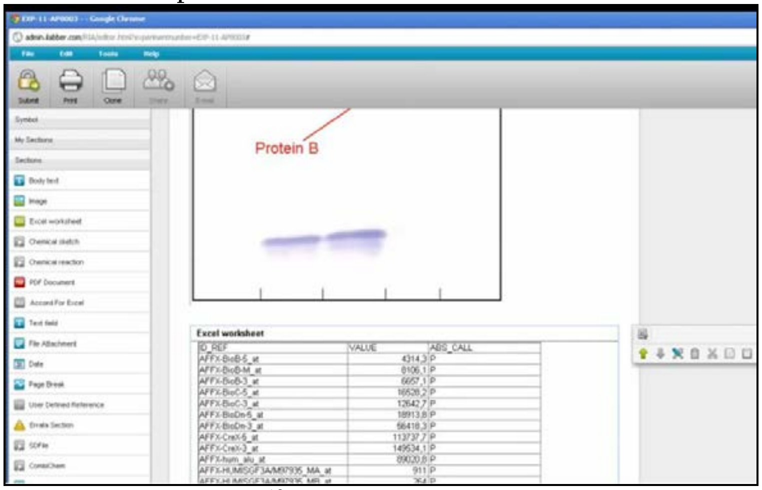


Figure 1. Screenshot from iLabber[10] including a figure and Excel worksheet.

eCAT[11] is an ELN with similar functions to iLabber, but has additional file structuring capabilities. In particular, a user may link records and files from their own server, as well as link files from the web. eCAT was one of the ELNs used in the Electronic Lab Notebook pilot study[12] at the University of Wisconsin, Madison. This study involved academic researchers, mostly graduate students, in fields of science, engineering, and medicine. A significant finding in the report is that the users found two features of most use: the ability to add data and link files. The simple drawing tools in eCAT were not deemed very useful by many of the users. Although the file structuring functions of eCAT may not be necessary for simpler undergraduate laboratories, given that practicing engineers found this useful, eCAT may be a good option for upper-level laboratories and students involved in undergraduate research.

Sophomore-Level Undergraduate Engineering Laboratory

During the 2011-2012 academic year, we implemented a transition from paperbound laboratory notebooks to electronic laboratory notebooks in an undergraduate experimental engineering course. Experimental Engineering (E80) at Harvey Mudd College is a sophomore-level, semester-long course, involving multiple experiments covering a number of engineering disciplines. The objectives of the course are to teach basic instrumentation and measurement techniques; good lab notebook practice; technical report writing; analysis and presentation of data; the usage of experimental results for engineering design purposes; and the beginnings of professional practice. The course explicitly requires learning in multiple disciplines but directs all of the experiments to a final goal: to build, instrument, and fly a small rocket; and analyze and report on the data collected during the flight. The course walks the students through modeling of the rocket performance based on weight, vibration, strength, drag, and engine test data; and the implementation and configuration of an instrument package and data acquisition system. The students have various objectives and constraints related to their scientific goals and project budget; therefore they are required to choose from among alternatives when designing their sensor package. Each student team builds and instruments a rocket, and test flights are made where the students collect experimental data. If weather conditions and the state of the vehicle permit (i.e., the rocket wasn't damaged or destroyed during flight or recovery), each student team may get data from up to six flights.

The course format consists of two large lectures, and two three-hour laboratory sessions per week. Course enrollment over the past five years has ranged from approximately 60 to 80 students per semester. These 60-80 students are divided into four sections of up to 20 students. The typical staffing for the course is one professor per 20 students. While this faculty-student ratio is considerably higher than that of most engineering programs, it is consistent with Harvey Mudd College's approach to undergraduate education. The students are placed in teams of four students, and perform their laboratory work as teams. The laboratory experiments in the course span various engineering disciplines. Electrical engineering and electronics is emphasized, since modern instrumentation and data acquisition relies heavily on those disciplines. Mechanical and aerospace engineering topics are also fundamental to rocket flight; in particular, fluid mechanics and trajectory modeling are important. The students are introduced to the National Instruments myDAQ[13] data acquisition system, and LabVIEW assignments are assigned to help the students learn its use.

The students learn basic electrical measurements and design/test an op-amp-based low-pass (anti-aliasing) filter. This filter can be used during the data acquisition phase of the launch. In order to prepare the students for the various instrumentation tasks, there are laboratories focusing on data acquisition (pressure, temperature, acceleration, and rotation-rate measurements) and the use of modern computer-based data-acquisition systems such as LabVIEW along with the myDAQ device. In order to develop the students' understanding of wind tunnel measurements, there is a lab involving drag measurements and calculations for standard shapes and the model rocket. The students also build on their introductory physics knowledge to model vehicle kinetics and flight trajectory, and also perform static engine tests on the model rocket motors to measure the thrust curve.

Our Implementation of ELN

Although there are many commercially-available ELNs, most have been aimed at satisfying the requirements of the pharmaceutical and biotech industries, and tend to include more extensive functions than those needed for an undergraduate laboratory course. For our initial foray into ELNs, we took the approach of using an already-existing course management platform (Sakai) as the electronic repository for the students' work, and allowed the students to submit their work using Microsoft Office Suite or similar word-processing tools. We urged them to investigate how to use the timestamp function in both Excel and Word. Sakai[14] is the free, open source course management and collaborative learning tool. It is an alternative to a traditional commercial course management system such as Blackboard. Collaboration and sharing of materials is a primary objective of Sakai. Students, staff, and faculty all have access to the system, and courses are automatically populated with enrolled students at the beginning of each semester. Sakai includes many functions, including blogs, chat rooms, forums, messages, podcasts, syllabus, and web content. For our ELN application, we used the "Assignments", "DropBox" and "Resources" functions. These functions allow users to store, manage, and share files online. File types can include documents, videos, and images. Citation lists can also be created in Sakai. Files 'dropped' into folders on Sakai are timestamped; faculty can also set assignment deadlines, and Sakai will report if a submission was turned in late. The students used Sakai to turn in work related to their lab notebooks; faculty and teaching assistants used Sakai to access the students' work in order to grade and release comments back to the students.

The primary reason for switching from PLNs to ELNs was because we believed that electronic recording would be the typical format students would be expected to use in industrial or research contexts, once they have graduated. We expected that the ELN format might improve students' written communication, given students more practice in submitting polished writing, rather than the hasty scribbling we sometimes see in the PLNs. We thought the electronic format would result in increased use of images and videos to document lab set-ups and operation. We were curious to see if the students would submit their spreadsheet files as documents reporting raw data and the processing of such data. These spreadsheets could be dropped into the "Resources" folder of the Sakai course management system, but this option was not suggested to the students. There were faculty concerns about students losing the ability to quickly sketch a schematic, although some instructors argued that the clever students could still sketch on paper, and then scan (or photograph) and insert the image into their document.

Examples of Student Work: PLN and ELN

We assessed laboratory notebook submissions of raw data, test set-up schematics, equipment lists, and comparison of experimental data to literature values. In this paper, we will focus on the first two (Cardenas[4] describes the rest of the assessment.) In assessing presentation of raw data in the lab notebooks, an excellent submission would include raw (not processed) data, with correct units labeled, and multiple trials. It was typical to see tables that showed only processed data, and data without any units whatsoever. The least acceptable submissions had no raw data, or included placeholders for raw data, but did not fill in the tables. Figure 2 shows an example of an entry in a PLN from E80. This is the typical 'placeholder' for raw data: the students knew they needed to enter raw data, and created a table for the raw data, but neglected to actually enter the data. We know they took the data, because processed data tables and graphs show up in their notebook.

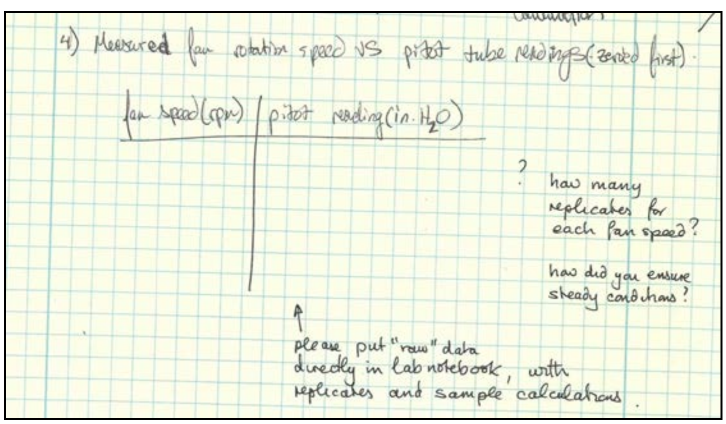
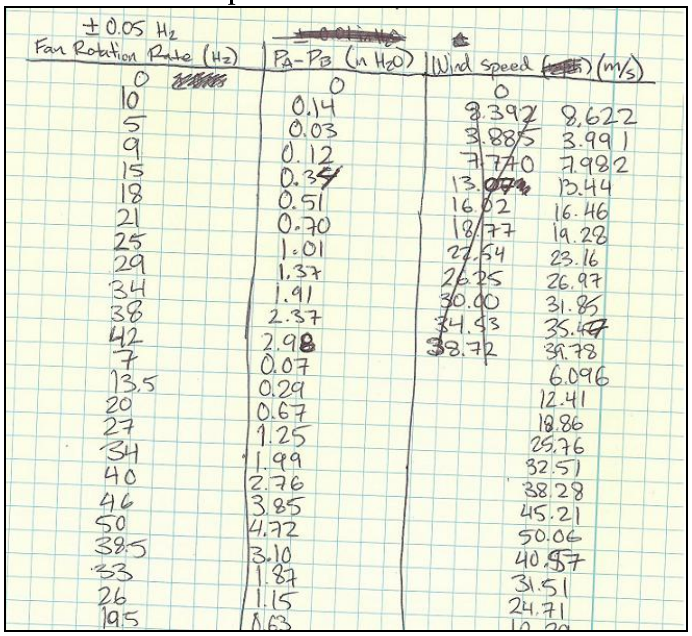


Fig. 2. Missing raw data in a PLN. Grader comments are seen on the right and bottom. A better example of a raw data table is shown in Figure 3. Here the students present the fan speed data; the raw measurement of pressure; and the processed data indicating velocity of the air in the wind tunnel.

Submission of raw data in ELNs was similar to that seen in the PLNs, although we didn't see any raw data placeholders; when raw data were not presented, they were simply absent from the document (ELNs were handed in .doc or .pdf formats.) Figure 4 shows a raw data table from an

ELN; the students did not pay attention to the document formatting, so the table was split across the page break, and the units were not specified for all the data.



Fan Rotation Rate (Hz) ±0.05 Hz	PA-PB (in H2O)	Wind speed (m/s)	
0	0	0	
10	0.14	8.392	8.622
5	0.03	3.885	3.991
9	0.12	7.740	7.982
15	0.35	13.07	13.44
18	0.51	16.02	16.46
21	0.70	18.77	19.28
25	1.01	22.54	23.16
29	1.37	26.25	26.97
34	1.91	30.00	31.85
38	2.37	34.53	35.47
42	2.98	38.72	39.78
7	0.07		6.096
13.5	0.29		12.41
20	0.67		18.86
27	1.25		25.76
34	1.99		32.51
40	2.76		38.28
46	3.85		45.21
50	4.72		50.06
38.5	3.10		40.57
33	1.87		31.51
26	1.15		24.71
19.5	0.63		[illegible]

Figure 3. Data table showing raw and processed data in a PLN.

RPM	Test1	Test2	Test3	Test4	Average	Std. Dev.

E80 Lab 5: Wind Tunnel – - 6

500	0.056 (498)	0.057 (503)	0.056 (501)	0.056 (501)	56.25 Pa	0.43
1000	0.238 (1001)	0.241 (1001)	0.238 (997)	0.240 (1001)	239.25 Pa	1.30
1500	0.560 (1502)	0.560 (1499)	0.564 (1503)	0.563 (1500)	561.75 Pa	1.79

Figure 4. Example of ELN data table with missing units and poor formatting.

Figure 5 shows a better example of a raw data table from an ELN. The figure shows some of the text from the ELN, as well as the data table showing raw (not processed) data, with units clearly and correctly labeled.

5.2 Wind Tunnel Calibration

The data collected using the pitot tube and the wind tunnel are seen in Table 8. Data was taken for speed controller settings from 0 to 75, but the pitot tube readings from the controller settings of 0 and 5 were zero and thus failed to produce meaningful results. Two trials of data were collected, one with increasing RPM and one with decreasing RPM to ensure reproducibility.

Speed Controller Setting	Fan Speed (RPM)	Pitot Probe Reading (in. H_2O)	Test Section Airspeed (mph)
10	64	0.00	0.00
15	198	0.01	4.51
20	411	0.06	11.05
25	601	0.16	18.04
30	783	0.30	24.71
35	971	0.48	31.25
40	1134	0.66	36.65
45	1289	0.87	42.07

Figure 5. Data table from an ELN showing raw data and units.

We also assessed the students' ability to describe the test set-up in their laboratory notebooks. The best examples include a sketch or picture of the test set-up, with equipment clearly labeled. For both ELNs and PLNs, common mistakes included presenting incomplete descriptions of the set-up, and neglecting to describe the setup whatsoever. Although we expected to see more hand-drawn sketches of test set-ups in the PLNs, occasionally students sketched on a piece of paper, and then scanned that and pasted the scan into their paper notebook. We also expected to see more photos included in the electronic versions, but the most common submission in both the PLNs and ELNs was no description of the test set-up. This is a significant deficiency that we need to address in future versions of the course.

Figure 6 presents a rudimentary sketch from students' PLN. Figure 7 shows a much better sketch, also from a PLN. Figures 8 and 9 show photos of the actual test set-up that students presented in an ELN. Although we did expect that students would use the ability to easily include photos in their electronic versions, it was not commonly seen. Again, the most common submission was no description of the test set-up.

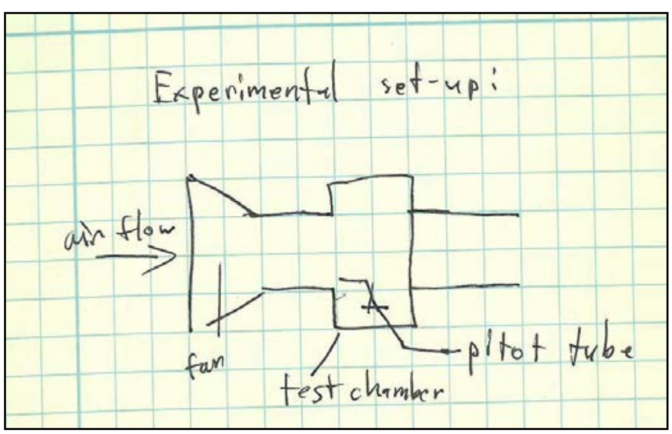


Figure 6. Rudimentary sketch of the test set-up from a PLN.

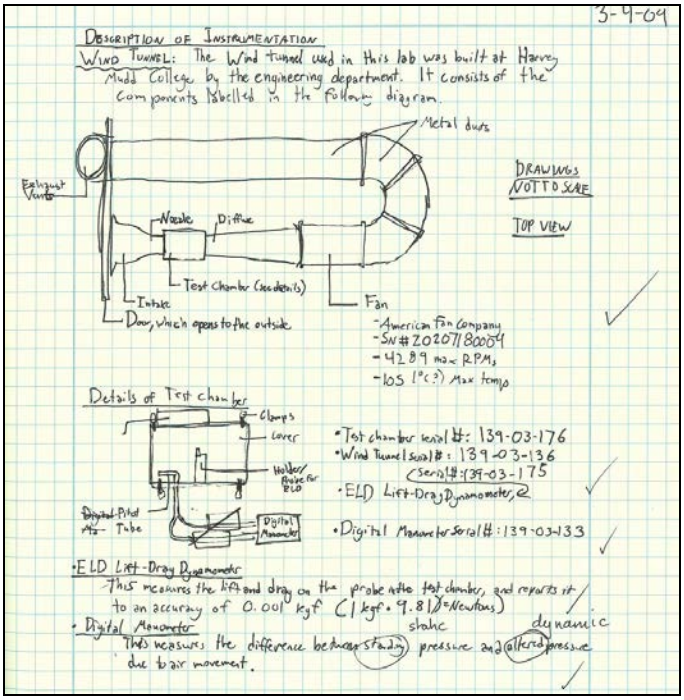
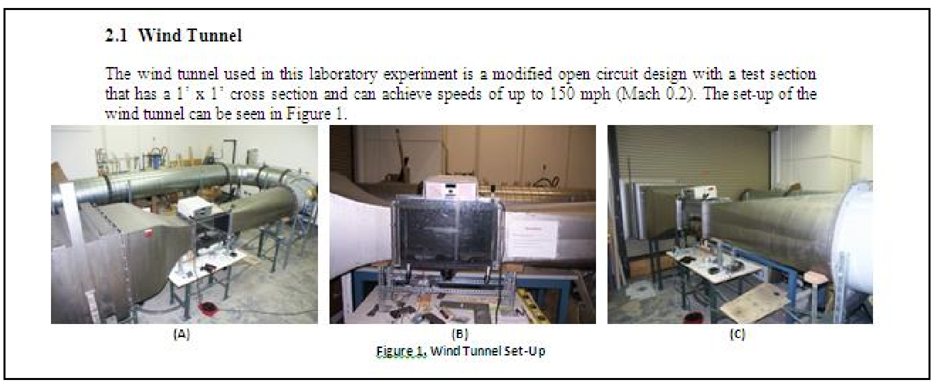


Figure 7. Much better hand-drawn sketch of the test set-up in a PLN.



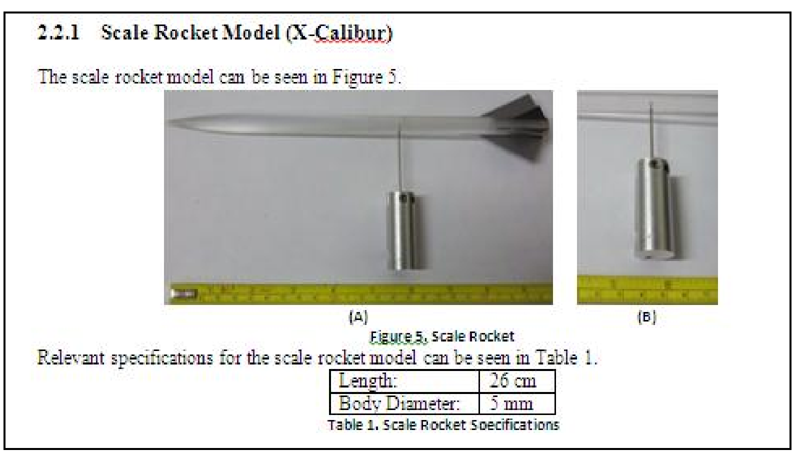
2.1 Wind Tunnel

The wind tunnel used in this laboratory experiment is a modified open circuit design with a test section that has a 1' x 1' cross section and can achieve speeds of up to 150 mph (Mach 0.2). The set-up of the wind tunnel can be seen in Figure 1.

(A) (B) (C)

Figure 1. Wind Tunnel Set-Up

Figure 8. Photos presented in the description of the test set-up in an ELN.



2.2.1 Scale Rocket Model (X-Calibur)

The scale rocket model can be seen in Figure 5.

(A) (B)

Figure 5. Scale Rocket

Relevant specifications for the scale rocket model can be seen in Table 1.

Length:	26 cm
Body Diameter:	5 mm

Table 1. Scale Rocket Specifications

Figure 9. ELN submission of photos presenting equipment used in the wind tunnel lab.

Discussion

Although we expected to see differences in the students' submitted laboratory work, once moving to the electronic laboratory notebook format, these differences did not manifest in the areas we assessed. Students did not commonly use the electronic format to include more images in their notebooks; they only rarely submitted raw data in spreadsheet form to the dropbox; electronic 'links' were rarely seen as part of the ELNs; and video evidence was generally not submitted. At the beginning of the course, the only suggestions we gave the students regarding ELNs was that timestamping was important. In future offerings of the course, we suggest increased instructor vigilance in reminding students of the various functionalities of Sakai; in particular suggesting that students can link video files to their ELNs, or use their mobile phone cameras to document test set-ups.

The students' notebooks showed major weaknesses regarding the inclusion of test set-up schematics, both in the paper form and the electronic form. It is not clear whether the use of ELNs alone will improve reporting of schematics; significant and sustained encouragement and inducement from the instructors is likely to have more impact than any changes in notebook format. Although some electronic devices allow sketching using a stylus, drawing by hand on paper still seems easier. As mentioned earlier, clever students could sketch on paper, and then scan or photograph the sketch in order to include it in their ELN, but this was not commonly seen. If we want to see this done, we will likely have to explicitly require it of the students. It should be noted that many students have been trained that there are significant differences between a 'lab report' and a 'lab notebook'. The course website explicitly asked for the students to submit a lab report, and therefore it is possible that students did not submit raw data because they have been told that lab reports do not include raw data (although other sections of the web site explicitly request submission of raw data.) Previous versions of this course at our institution have not made a clear distinction, although those were all paper-based, which may have steered students towards the 'lab notebook' mindset. Again, explicit instructions on the instructors' parts could make a difference here. Since the outcomes assessed were not able to distinguish differences between the electronic and paperbound notebooks, future work should be done to assess learning outcomes that may be able to identify differences between the two media. These could include examination of students' perceptions between the types of notebooks; time spent inputting data and text; quality of written work; and the ability to access their work outside the laboratory.

Implementation: Challenges and Successes

The course management system, Sakai, has its detractors, including some of the faculty teaching this course. It is possible that there may be instructor "push-back" if these instructors are asked to sincerely recommend increased Sakai usage by students, even though the system is in wide use on campus. If students submit other types of files (spreadsheet-based data files, video files, etc.), students would drop those files into the "Dropbox" portion of Sakai, and their ELNs would be submitted into the "Assignments" folder, which is a completely different part of the system. A good ELN would allow linking between these files, but it does not seem to be a function of Sakai at this point. A course management system or commercial ELN that makes uploading and linking various files is recommended, given that expecting faculty to hunt for these additional media types on Sakai may be an unreasonable request.

Initially, students had difficulty with submitting their work to Sakai. A common occurrence was seen with submissions of Microsoft Word documents; some documents lost all formatting and equations once submitted to Sakai. A workaround for this was simply to save the Word document as a pdf, and upload the pdf. Another unknown bug was that multiple or duplicate files were often seen in the students Assignments folder; this was not a major problem, but it was strange. Submission of work was often recorded as being late by Sakai; again it was not clear if the server clock was slightly off, or if students really were submitting their work a minute or two late. Students often responded to the notification of late submission by sending multiple emails to the instructors, insisting that they had submitted the work on time. The lab notebooks were graded by faculty and by teaching assistants (the teaching assistants were upper-class engineering students who had previously taken the Experimental Engineering course.) The grading process was simplified by the use of the ELNs, due to the ability to access the students' work via networked computers, as opposed to grading PLNs, where the graders physically remove the lab notebooks from the lab (thus making the notebooks unavailable to other graders, and to the students themselves.) Although some faculty had difficulty with accessing the ELNs from Sakai, this was solved by making sure experts in Sakai (for example, administrative assistants in the departmental office or other faculty) were available to download the students' work for those instructors.

Regarding the claim that the ability to easily search ELNs is a huge asset, we found that having the work stored on Sakai made it much easier to archive and search, especially compared to manually searching through hundreds of paper-bound notebooks. The PLNs needed to found and then brought out of storage on a hand cart, and occupied a physical volume of ~2 m^3. Having access to the students' notebooks in an electronic form made the research done in this paper much more convenient. Although the students' ELNs were not centrally located in a single folder, it was not too much work to organize the files into a more convenient file structure, and although the file formats were not consistent, it was still possible to do a reasonable electronic search of these files.

Conclusions

The "dream" ELN would include seamless communication between various instruments, data acquisition systems, and electronic storage. As noted in the literature[15,16,17], given the variety of experimental systems, no single ELN solution exists that will automatically work with a custom experimental set-up. However, better ways to link, store, and organize various file types using a course management system would improve the implementation of an ELN in a lab-based course. Since ELNs are likely a new experience for most students and faculty, explicit requirements or marked suggestions regarding their use are likely necessary. For example, strongly suggest to students that test set-ups be sketched (and scanned) or photographed, and then included in their Word file and/or electronically stored and linked to their ELN. Give multiple reminders that raw data need to be recorded in their spreadsheet programs, and those files uploaded to the course management system as part of their ELN. Depending on the instructor objectives regarding laboratory templates, using a commercial ELN that explicitly lays out the recommended notebook sections could be one way to remind students what they are expected to report from their experiments. Clarity on the differences between a lab report and a lab notebook would do much to alleviate potential student confusion. It may also be necessary to make sure instructors have assistance in learning and navigating the ELN software and course management systems, so that the tools do not interfere with the delivery of course content and assessment of student work.

Using the course management system as a means of implementing an ELN in the experimental engineering course improved the instructors' ability to access, grade, and search the students' work. Archiving these lab notebooks will only require electronic storage (although if we decide to keep these for decades, we will need to be mindful of keeping the files in a readable format). In our assessment of four semesters of student work, we saw no marked difference between work submitted using ELNs versus PLNs when we assessed submission of raw data and inclusion of test set-up. However, further assessment should be done to determine if the quality of written communication and other learning outcomes were affected by the use of ELNs.

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