An Experience with Electronic Laboratory Notebooks in Real-World, Client-Based BME Design Courses

Dr. John P Puccinelli, University of Wisconsin, Madison

Dr. Puccinelli is an Associate Faculty Associate in the Department of Biomedical Engineering. He began here as student near the start of the UW-BME program and earned his BS, MS, and PhD in BME. He is interested in hands-on instruction – teaching and developing courses related to biomaterials and tissue engineering, as well as design. He was awarded the BMES Student Chapter Teaching Award in 2011 and 2013 and the Polygon Outstanding BME Instructor Award in 2012.

Dr. Amit Janardhan Nimunkar, University of Wisconsin Madison

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Abstract

We implemented LabArchives Electronic Laboratory Notebook (ELN) in three levels of Biomedical Engineering (BME) Design (sophomore – senior) at the University of Wisconsin-Madison. Paper notebooks allow users to quickly take notes, make design sketches, and show mathematical calculations within them, however they are limited in their ability to incorporate the vastly growing types of various digital media being employed in engineering design. Additionally, only one copy of a paper notebook exists as compared to the ability to share an ELN (or part of one) with the involved parties. Here we outline the processes used to implement the ELN and initial student and faculty survey results comparing paper notebooks to an ELN.

Introduction

Our Biomedical Engineering (BME) undergraduate students participate in real-world, client-based design projects throughout the curriculum in teams of four or five students.[1] The design curriculum is advised by up to 13 faculty members per semester, each overseeing up to four teams. In these courses, from sophomore through senior year, the students not only gain real-world design experience, but also learn and practice professional engineering design skills including maintaining a laboratory or design notebook. The design notebook protects the student's intellectual property and is therefore essential to our campus patenting agency for both applying for and defending patents. The notebook also details the research and the procedures for use by the project's client while subsequently implementing or continuing a design; it also serves as a tool for faculty to assess individual students and to establish their contributions to their team. Proper use of the laboratory notebook builds the life-long learning skills necessary for a student to become a successful design engineer or a researcher.

Traditionally, the department provided students with physical design notebooks, which facilitated uniformity, met the standards for design work, and were convenient for the students to carry and quickly present design ideas and to take notes. Unfortunately, the students were all too often more concerned about the course notebook grade than its true purpose. Thus, many did not complete their notebook in real-time, but rather kept notes and sketches separately and then copied them neatly into the notebook just before the due dates. Additionally, during these grading times, the students would be without their notebooks while the faculty reviewed them, thus hindering their ability to keep them up-to-date. They were also unable to 'share' common notebook entries easily, such as group meeting notes. Similarly, only one set of team notebooks existed and therefore typically either the client, the student, or our patent agency held the single set. Finally, as the number of undergraduates in the department has grown and continues to grow, the cost and management of the many physical notebooks has become onerous. In this digital/online age, our BME Student Advisory Committee (BSAC) expressed interest in using laptops/tablets as design notebook portals, as many of the students were already creating digital content by typing their notes, using CAD software to generate design sketches, or writing software code as part of their design solution (which is marginally useful when printed into a paper notebook).

As a result, in fall 2013, we experimented for the first time with LabArchives Electronic Laboratory Notebooks (ELN) in all three of our design courses (sophomore, junior, and senior) which consisted of approximately 200 students in total. While there have been various ELNs developed for research laboratories, few are priced for student use or geared toward classroom instruction while appropriate for the multidisciplinary BME design projects (some include: chemistry, biology, mathematics, code, etc.). ELNs in general provide automatic time stamping (to protect intellectual property), revision history, a rapid method of entering data, content organization in a neat and easy-to-read fashion, compatibility with an abundance of file types, and content sharing across notebooks. LabArchives has built-in instructor features that allow design advisors to view their students' notebooks, activity feed, and to generate a pdf copy of the notebook. Smartphone apps are also available that provide for uploading photos seamlessly and for making voice and real-time entries. Here we will present, from both student and faculty perspectives, the trials and tribulations of switching to ELNs for all of our design courses. We will summarize student feedback and provide preliminary assessment data.

Methods

Choosing an ELN platform

In choosing an ELN from the plethora of available options (nearly 100 unique options referenced),[2, 3] two main logistical criteria were considered for our particular unique six-semesters of design courses. First, the design course instructors needed the ability to view and grade their own design team's notebooks. Ideally, each instructor would only see their teams and the ELN would group the teams for the instructor. Thus the grading process would not be onerous for the instructors. Second, the ELN should not be cost prohibitive as many of the ELNs cost near $100 per licensed user. Current paper notebooks provided by the department cost $15 per notebook and this was set as the budget. Notebook functionality was then considered including the ability to easily import various content (CAD drawings, Microsoft Suite integration, images, and others.), name and time-stamping of entries (for IP protection), and sharing of entries.

Our institution also hosted ELN vendor seminars. LabArchives-Electronic Laboratory Notebook[4] classroom edition emerged as a solution that would meet all of our needs at this time. Most other options lacked instructional management of 'students' within a course. Some could offer a similar structure through lab-like organization (i.e. Lab PI and graduate students, etc.), however managing student teams and multiple instructors would have been complicated. Also, more general online note taking programs such as EverNote, Microsoft OneNote, or even Google Docs/Drive were considered, in addition to lacking course management features these lacked the official nature of notebooks in their ability to protect intellectual property (time stamping, identification of the content creators, revision history and/or signed/locked entries). After choosing LabArchives for Design other vendor ELNs were also evaluated by our institution as part of pilot project, however under a confidentiality agreement we are not permitted to disclose any information from this process, therefore this paper focuses on our experience with LabArchives in BME Design. LabArchives will also be employed in our spring sophomore design fundamentals course where students used it as both a design notebook and laboratory instruction manual.[5]

ELN implementation

Using the notebook grading sheet, a notebook file/folder structure "Master course notebook" was created before the semester. This included folders for project information (subpages: contact information and project description), meeting notes (subfolders: team, client and advisor meetings), research notes (subfolders: biology/physiology and competing designs) design ideas, testing and results (subfolders: materials/expenses, protocols, and experimentation), and references. A sample entry was also provided which included bolded headings for title, date, those present, goals, notes, and conclusions/action items. Students are able to create new folders or modify existing folders. Additionally, if changes or additions were made to the master course notebook, the instructor could 'push' this change to all student notebooks or use this feature to selectively release content to the students.

Our design students in all classes (sophomore-senior, BME 200,300, 400) meet together on the first day of class to choose their design projects using a student created web-based application. As a result, project teams and associated instructors are not finalized until the end of this class-period. Thus, despite the LabArchives software allowing for easy class and section import, this could not be accomplished with our course structure. To avoid any delay in the students accessing their notebooks, all course rosters (200 students) were imported and the students were given instructions to create their accounts before this first class day. At the start of class, a brief 15 min tutorial was provided by the design instructors. This included the importance of notebooks, context and history of paper notebooks, the folder and file structure of LabArchives, the sample format, how to create various entry types (rich text, attachments, Microsoft Suite documents, and importing references from PubMed), sharing entries, linking between entries, the iOS and Android apps, and an overview of the help documents. Once all of the projects were selected, the project, the student, and the instructor list were exported from our software and LabArchives sorted the students into the proper 'sections' with one section for each design project and each instructor being assigned their sections or projects. Instructors could then login and see each of their design teams (Figure 1).

Figure 1: Screenshot of LabArchives "Course Manager" showing the course notebook folder structure on the left and the course manager features on the right including the students assigned to team '7-Sleep Apnea' as an example (student names were greyed-out). For each student, it also displays their activity (number of entries), their latest action and provides links to view a complete chronological activity feed, the entire notebook, or comments.

As with paper notebooks, instructors provided grades to their students at mid-semester and end of the semester. LabArchives allows the students or the instructors to generate a pdf copy of the notebook that can be easily scrolled through for this purpose. Instructors could also just view the online notebooks. Unlike paper notebooks, instructors could view the notebooks at any time (such as before design meetings) to provide constant feedback and gain insight into the project progress. Unlike paper notebooks, students were never without their notebook during grading.

Assessment of the ELN

Throughout the semester, BSAC provided feedback to the design faculty on the ELNs. Desired features that were lacking or any concerns were directly communicated to the LabArchives development team and these features were implemented or addressed quickly. An example feature that was missing in LabArchives and requested by the students was the 'autosave' feature. The LabArchives development team implemented this feature into the ELN on request. At the end of the semester both the students and the faculty were surveyed. All surveys were anonymous and consent to use the anonymous data was obtained for IRB approval. Since the majority of the students used paper notebooks either in their freshman design course, pervious BME design course(s), and/or during their employment (i.e. internship or co-op) they could make a direct comparison. They were asked to rate a number of criteria, on a scale of 1-3 (where 1 is poorly, 2 is moderately, and 3 is very), related to logistics and the engineering outcomes used to grade the notebooks for both paper and electronic notebooks. Environment plots were generated to show the relationship between the two formats. For students who had never used a paper notebook, they rated only the electronic notebooks and this data was analyzed separately.

Results and Discussion

Implementation

The process to set-up the semester (Master course notebook, student design team import, associating instructors, and preparing the in-class demo) was a simple process lasting for about an hour. The post-course ELN survey was taken by 92% of the BME design students (170 students) and 98% of them had never used an ELN before this course while 91% had previous experience with paper design or laboratory notebooks. Even though such a large number had never been exposed to an ELN, 59% of the students only needed the 15 min in-class demo to feel comfortable using it. An additional 36% spent less than four additional hours learning how to use it by helping each other and utilizing the LabArchives online help documents and videos. Only 6% found it *somewhat difficult* or *difficult* to use with 41% finding it *easy* to *very easy* to use and 34% found it *somewhat easy* to use. Unfortunately, 10% noted some type of technical difficulty (typically as a result of losing internet connectivity causing loss of data). This particular issue was raised in a BSAC meeting and an 'autosave' feature was requested through LabArchives that is now available. The students felt that overall the ELN was simple to learn and easy to use.

Assessment

Environmental plots were used to compare the ELN (y-axis) to the paper notebooks (x-axis). Points along the 45° meridian line represent areas where each notebook are equal in comparison. Scores in the upper right quadrant are areas where both the ELN and paper notebooks are

moderately to very proficient. The upper left quadrant contains areas where the ELN is superior and the lower right quadrant are areas where the paper notebooks were superior.

Logistical considerations of using either a paper notebook or ELN were scored in the survey by the students and the faculty (Figure 2). The ELN outscored the paper notebook by the students and faculty in areas such as being accountable to keep it up-to-date, the ability to maintain neatness, organization, draft revisions, share content and link to and include outside materials. Sharing, organization, and linking were the areas cited as the most beneficial features of the ELN. In fact, 82% of the students shared their notebooks (half of which shared the entire notebook) with their teammates. The faculty felt that students could format the ELN better than the paper notebooks, however while the students thought highly of the ELN formatting, they also felt they could decently format their paper notebooks. The students also commented frequently that they appreciated the ELN due to their poor handwriting and the available spell check feature.
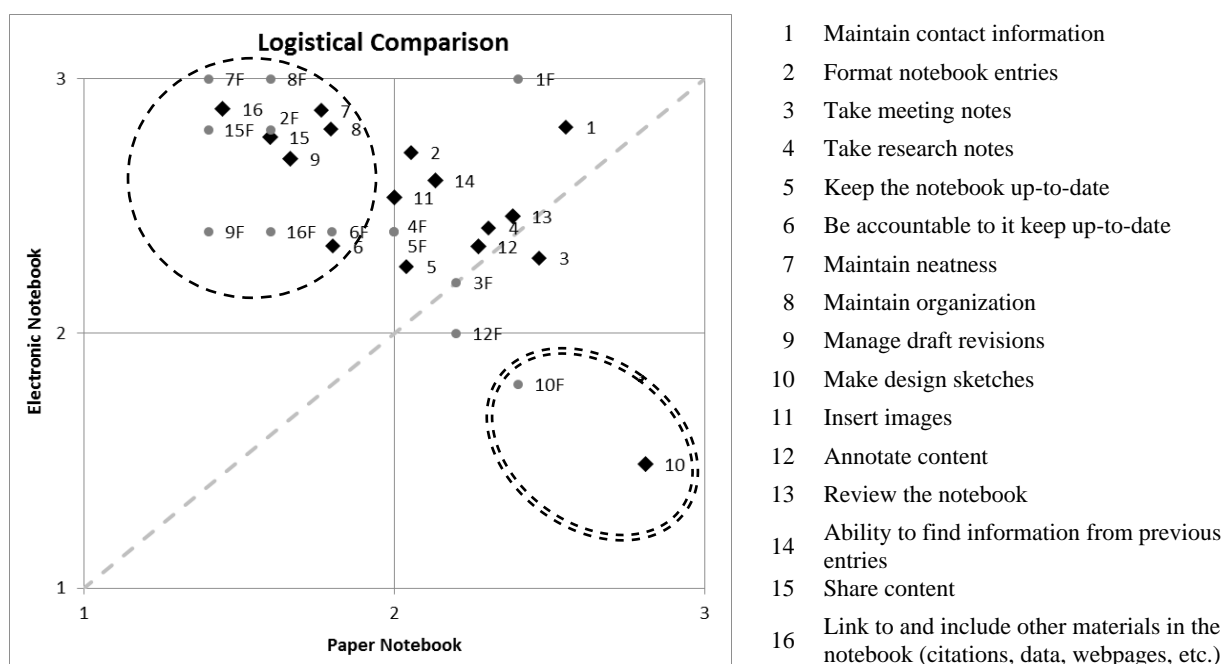

1	Maintain contact information
2	Format notebook entries
3	Take meeting notes
4	Take research notes
5	Keep the notebook up-to-date
6	Be accountable to it keep up-to-date
7	Maintain neatness
8	Maintain organization
9	Manage draft revisions
10	Make design sketches
11	Insert images
12	Annotate content
13	Review the notebook
14	Ability to find information from previous entries
15	Share content
16	Link to and include other materials in the notebook (citations, data, webpages, etc.)

Figure 2: Logistical considerations of using the notebooks: survey results for students rating their experience (♦) and faculty rating how well the students did (●) on a scale of 1-3 (1: poor, 2: moderately, 3: very). Each data point is also identified with labels corresponding to the list on the right, with the faculty data points including an 'F' for faculty i.e. 1F. Scores in the upper left quadrant indicate that the ELN is far superior (single dashed circle) in a number of categories. Whereas scores in the lower right quadrant indicate that the ELN is inferior (double dashed oval) which included only category #10 the ability to make design sketches. Scores were consistent between students and faculty in most categories.

The only point where the ELN lagged behind the paper notebook was in the area of making design sketches. The sketching program provided in LabArchives is extremely rudimentary and not useful. Most students would make design drawings in SolidWorks or other drawing/CAD programs and include those as images or sketch by hand and then use one of the apps with their mobile device to upload a photo of their sketch. Inclusion of a more robust drawing program

within the ELN would be a benefit, however most students indicated they would still use one of these aforementioned methods. Additionally students commented that they felt rude using their laptops during meetings with their clients or other professionals and preferred paper notebook in these situations. Many then transposed these paper notes into the ELN. Also a few commented that their laptops were heavy to carry around or had poor battery life resulting in them using paper and transposing into the ELN later.
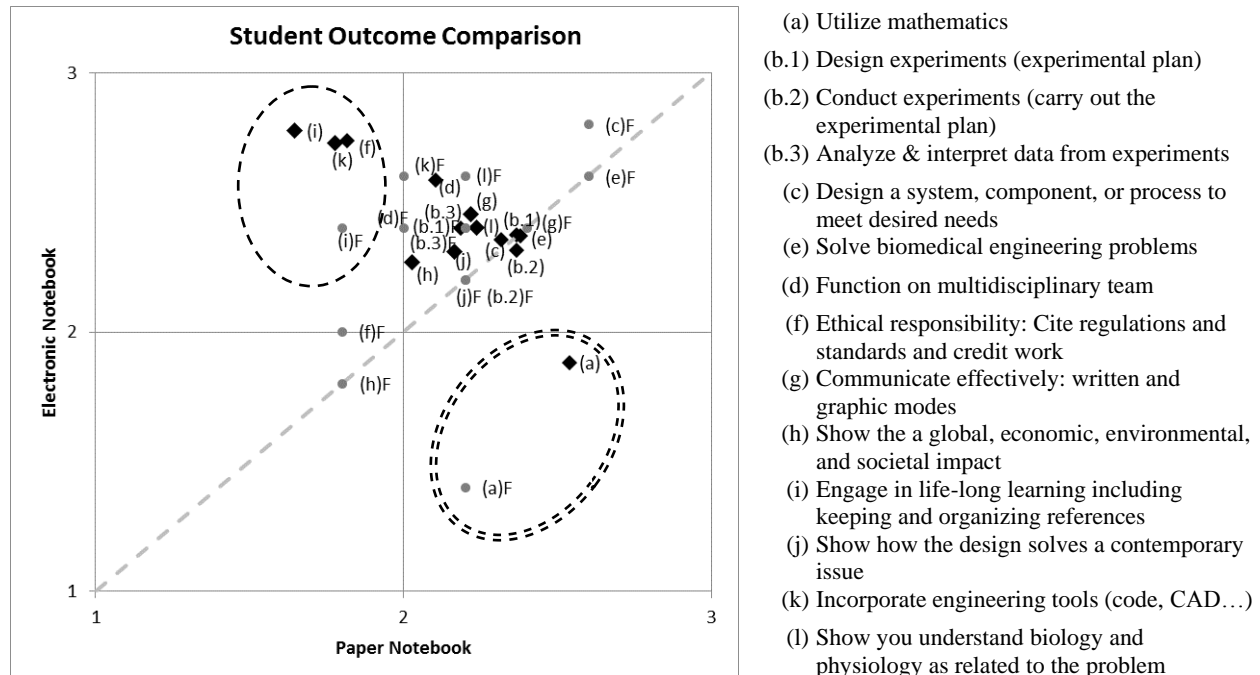

(a) Utilize mathematics
(b.1) Design experiments (experimental plan)
(b.2) Conduct experiments (carry out the experimental plan)
(b.3) Analyze & interpret data from experiments
(c) Design a system, component, or process to meet desired needs
(e) Solve biomedical engineering problems
(d) Function on multidisciplinary team
(f) Ethical responsibility: Cite regulations and standards and credit work
(g) Communicate effectively: written and graphic modes
(h) Show the a global, economic, environmental, and societal impact
(i) Engage in life-long learning including keeping and organizing references
(j) Show how the design solves a contemporary issue
(k) Incorporate engineering tools (code, CAD…)
(l) Show you understand biology and physiology as related to the problem

Figure 3: Engineering student outcomes using the notebooks: survey results for students rating their experience (♦) and faculty rating how well the students did (●) on a scale of 1-3 (1: poor, 2: moderately, 3: very). Each data point is also identified with labels corresponding to the list on the right, with the faculty data points including an 'F' for faculty i.e. 1F. Scores in the upper left quadrant indicate that the ELN is far superior (single dashed circle) whereas scores in the lower right quadrant indicate that the ELN is inferior (double dashed oval) for only outcome (a) the ability to utilize mathematics. Scores were relatively consistent between students and faculty.

In the design course, the faculty score the students on most deliverables (including the notebooks) using our ABET outcomes (a– l). Similar to the logistical considerations we surveyed the students and faculty on the student's performance in the notebook on these outcomes (Figure 3). Most outcomes scored well and similarly between the paper notebook and the ELN. The ELN scored higher on the ability to cite regulations and standards, credit work, keep and organize references, and incorporating engineering tools such as CAD and software code. Students commented that they appreciated being able to import references from PubMed, have functional links to resources, and being able to directly insert media (verses taping printed copies). However, like the ability to make design sketches the ability to utilize mathematics scored low for the ELN. This again is likely due to the rudimentary equation editor available in LabArchives. Many students again used paper and then captured a photo of their mathematical calculations and inserted into the ELN. Integrating the ELN with MATLAB, Mathematica, Maple, or other similar math program would be a significant benefit.

For students who had never used a paper notebook before, the average score for ELNs in most logistic categories and outcomes decreased, however, all criteria still remained in the same quadrants (date not shown). The ability to make design sketches and utilize mathematics was still a concern for the ELN. Overall the most requested features missing were a better sketching tool, integration with a math program and citation manager, and improved image integration and annotation tools.

The students felt that on average the number of entries were higher and the quality of entries were superior in the ELN. Interestingly, faculty felt the ELN would help prevent procrastination in that students would make more entries in real-time directly in the notebook verses entering data later (especially right before the deadlines). However, a similar number of students felt they made more real-time entries in paper and in the ELN and many felt it was the same for both. This is contrary to their belief that they felt more accountable to keep the ELN up-to-date. In the end, 76% of the students (and 100% of faculty) want to continue to use LabArchives and only 13% of students want to use paper again.

Finally, from the instructor's point-of-view (Figure 4), it was easier to view the students' notebooks with the ELN (not having illegible notebooks due penmanship was also cited as a benefit). The ELN also outscored the paper notebooks in the ability to perform notebook checks outside of class meetings, finding information within the notebooks and grading them.
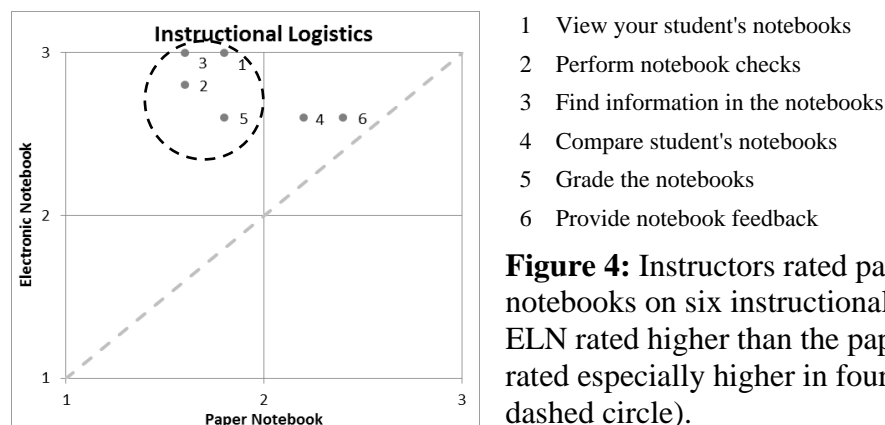

1 View your student's notebooks
2 Perform notebook checks
3 Find information in the notebooks
4 Compare student's notebooks
5 Grade the notebooks
6 Provide notebook feedback

Figure 4: Instructors rated paper and electronic notebooks on six instructional capabilities. In all, the ELN rated higher than the paper notebooks. The ELN rated especially higher in four (as indicated by the dashed circle).

Conclusion

The use of LabArchives in Biomedical Engineering Design courses (sophomore-senior) proved to be valuable experience. Both the student and faculty responses were overwhelmingly positive from a logistical, engineering, and instructional perspective. The ability for the students, the client, and the instructors to view the notebooks at any time and to all be able to keep the 'notebook' indefinitely is an additional major benefit. Two main concerns surfaced and were consistent between student who had and had never used paper notebooks before; using an ELN hindered the ability to directly make design sketches and utilize mathematics within the notebook. We will continue utilizing LabArchives in the spring design courses. We are also going to evaluate outcome achievement by comparing notebook evaluation form scores from past years to this year. Finally, we are also going to employ LabArchives in our new BME 201: Biomedical Engineering Fundamentals and Design sophomore level guided design course[5] as the course manual, repository for assignments, and design notebook.

Acknowledgements

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