Electronic Lab Notebooks Impact Biomedical Engineering Students' Quality of Documentation and Technical Communication

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Abstract

Laboratory notebooks have long been used as a tool to develop student documentation and technical communication skills in laboratory courses. Given the presence of social media as well as other methods of electronic communication, computer mediated activities provide an opportunity to educate students in a familiar setting. For this reason, we have pursued a study to measure the impact of electronic laboratory notebooks (ELNs, LabArchives Classroom Edition) on the quality of upper-level biomedical engineering students' documentation and technical communication skills. A total of thirty-three ELNs submitted by students enrolled in a biomechanics lab course during autumn 2016 and thirty-three paper-based notebooks submitted by students enrolled in the same course during autumn 2015 were selected for this study. Notebooks were quantitatively analyzed against a rubric designed to measure how well the selected notebooks met assessment criteria in the categories of *communication, documentation* and *presentation.* Results showed significantly higher overall mean and category-specific scores for ELNs compared to paper-based notebook submissions ($p < 0.05$). It was concluded that lab notebook keeping in an electronic format may be an effective medium for aiding students in improving documentation and technical communication skills.

Introduction

The use of cloud computing, digital technology, and social media has increased in education, scientific research, and the Science Technology Engineering and Mathematics (STEM) industries [Guerrero 2016; Machina 2013; Pence 2016]. ABET has indicated that preparing engineering students in technical communications is one of the essential skills needed to enter these fields [ABET 2016]. As a result, technical communication in the electronic setting may be a critical skill for engineering students seeking employment.

One way for students to gain and practice documentation and technical communication skills in a practical setting is through the experiential courses throughout the curriculum (i.e. laboratory courses). In autumn 2016, we transitioned the biomedical engineering laboratory course, biomechanics, from paper-based to electronic-based laboratory notebooks (ELNs) using LabArchives Classroom Edition.

The role of ELNs is similar to paper-based lab notebooks in which students practice record-keeping in a laboratory setting. In order to properly keep records, students practice collecting, storing, and presenting data, as well as summarizing their methodologies, observations, and results. However, the effectiveness of ELNs on improving the quality of biomedical engineering students' documentation and technical communication is not well studied. Therefore, the purpose of this study is to determine whether the ELN format improves biomedical engineering students' documentation and technical communication skills, compared to a more traditional paper-based laboratory notebook format.

Methods

Participants in this study were junior and senior level biomedical engineering undergraduate students who were enrolled in the biomechanics lab course during autumn 2015 or autumn 2016. The students enrolled in the autumn 2015 cohort were required to keep lab notebooks on paper, whereas those enrolled in the autumn 2016 cohort were required to keep electronic lab notebooks (ELNs) using department-purchased subscriptions to LabArchives Classroom Edition. Otherwise, all other aspects of this course, including instruction and student learning objectives, were identical. There was also no significant difference between overall final laboratory scores of both student cohorts ($p=0.78$), indicating a similar caliber of students and thereby presenting a reasonable comparison group for this study.

During both semesters of the biomechanics laboratory, students conducted a series of experiments spanning over four separate course meeting days. Although experiments were completed in groups of two or three students, each student was required to maintain their own individual laboratory notebook. Students were instructed to record under prescribed headers in their paper or electronic lab notebooks, namely "Title," "Objective," "Materials and Methods Notes," Observations and Other Notes," and "Data." In both semesters, an example lab notebook with guidelines for information to include under each header was provided to the students.

After each laboratory session, students received formative feedback from a teaching assistant on ways to improve their lab notebooks. This feedback was verbal when the notebooks were paper-based (autumn 2015), whereas the ELN format allowed for electronic feedback to be provided via rubrics the instructors created and imbedded within each student ELN (autumn 2016). An example of a student feedback rubric is shown in Table 1. Students were expected to use feedback to improve documentation in their entire notebook (ELN format) or in future entries (paper-based format). At the end of the course, students submitted their finalized paper-based or electronic lab notebook for summative assessment. Students could earn a total of 20 points based on the "points possible" scores associated with the student feedback rubric, as shown in Table 1.

Table 1: *Student feedback rubric for laboratory notebooks*

Section	Requirements	**Points Possible**
Title & Objective	Clearly captures the daily goal(s) of the lab	3
Materials & Methods	Descriptions of experiments & materials clearly provided	4
Results & Discussion	All data, graphs, & relevant discussion is documented	4
Observations, Notes	Observations, errors, & future improvements are detailed	3
Presentation	Notebook is neat, organized, & has labeled tables/figures	3
Improvement	All instructor feedback was implemented	3
	Total	20

After the conclusion of the lab courses, thirty-three student lab notebook submissions from each of the autumn 2015 and 2016 offerings were analyzed to determine whether the notebook format (paper vs. electronic) impacted the quality of students' notebook documentation and technical communication. This new assessment was performed using a second rubric (Table 2), which the authors developed to address three categories: *communication, documentation* and *presentation*.

Each rubric category included several assessment criteria, against which each student notebook was rated. Full (2), partial (1), or no (0) credit was given for notebooks meeting, partially meeting, or not meeting each assessment criteria, respectively. A few notebooks were given 1.5 and 0.5 credit to address distinctive responses. For consistency, this rubric assessment was completed by the same individual on each of the sixty-six notebooks.

In the *communication* category, lab notebooks were assessed by five criteria. A notebook that fully met each criterion must have included 1) a clearly written daily objective, 2) background information that clearly supported that objective, 3) a clear description of the experiment(s) being performed, 4) a clear purpose for each experiment, and 5) overall written communication that met instructor expectations. In the *documentation* category, lab notebooks were assessed on the detail of experimental methodology provided, the clear documentation of all observations, and the completeness and overall quality of documentation. Finally, the lab notebook's overall *presentation* was evaluated. All raw data were to be appended, and overall notebook presentation must have been well-organized and met instructor's expectations.

All quantitative rubric assessments were recorded in excel for each student notebook (n=66), where the maximum, minimum, and average for each assessment criteria were also calculated. T- tests ($\alpha = 0.05$) were performed using MATLAB to compare the paper vs. ELN rubric scores.

***Table 2**: Lab notebook documentation & technical communication rubric for one course meeting*

Category	Assessment Criteria	**Meets (2)**	**Partially Meets (1)**	**Does Not Meet (0)**
Communication of Experiment(s) and Purpose	Daily overall objective is clearly written			
	Background info clearly supports daily objective			
	Description of experiment(s) is clearly provided			
	Purpose of each experiment is clearly written			
	Overall written communication meets expectations			
	Subtotal (out of 10)			
Documentation of Experiments	Methods are documented in appropriate detail			
	Experimental observations are clearly documented			
	Documentations of all experiments are provided			
	Overall quality of documentation meets expectations			
	Subtotal (out of 8)			
Overall **Presentation**	All raw data is appended to the notebook			
	Organization of the notebook is logical			
	Overall notebook presentation meets expectations			
	Subtotal (out of 6)			
	Overall Score (out of 24)			

Results

The paper-based (autumn 2015) and electronic laboratory notebooks (autumn 2016) from the biomedical engineering biomechanics lab course were analyzed using a rubric that was designed to evaluate the quality of students' documentation and technical communication. Analysis revealed a significantly higher overall mean rubric score for the ELNs compared to the paper-based notebooks ($p < 0.05$). As depicted in Figure 1, the electronic laboratory notebooks received 86.3 ± 5.5, while the paper-based notebooks received 70.9 ± 9.8, out of 96.0 possible rubric points.

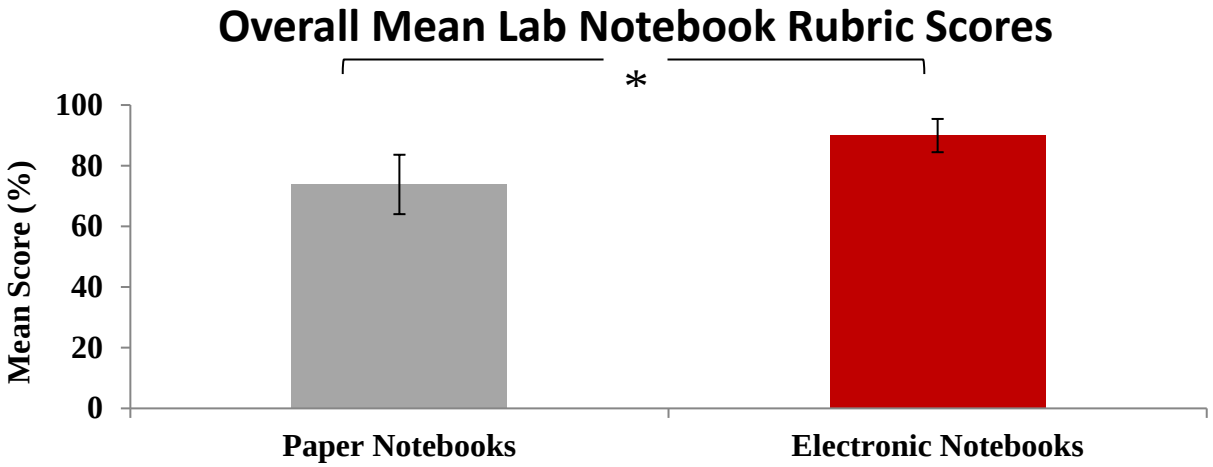

Figure 1: Laboratory notebooks kept electronically yielded a significant higher overall mean lab notebook rubric score (86.3 ± 5.5 out of 96.0) compared those kept using a paper-based medium (70.9 ± 9.8 out of 96.0). Rubric scores are presented as percentages. The rubric assessed quality of communication, documentation and presentation. (*) $\alpha = 0.05$.

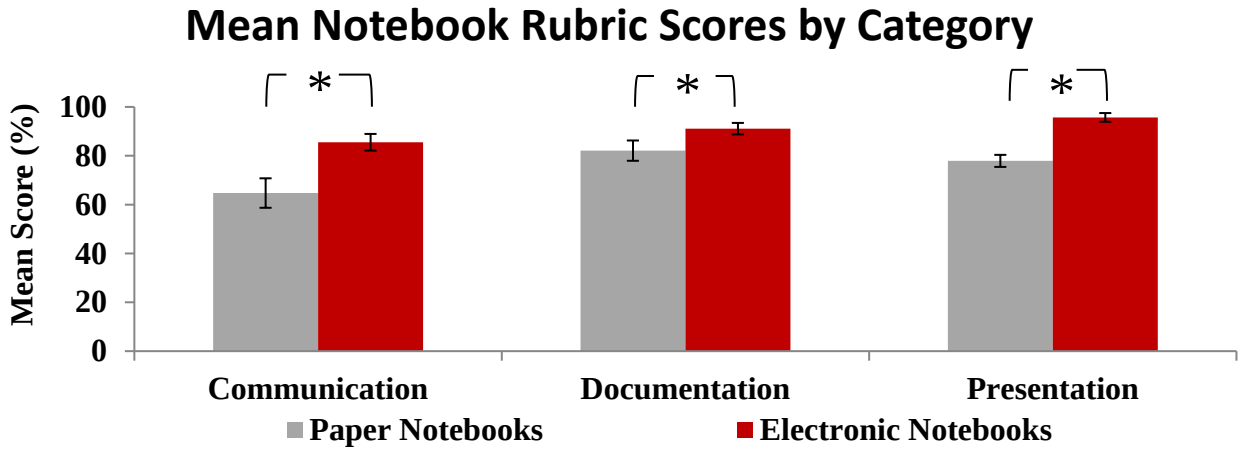

Figure 2: Student electronic lab notebook submissions significantly outscored paper-based notebook submissions in all three rubric categories (communication, documentation and presentation). (*) $\alpha = 0.05$.

Performance in each rubric category was also found to be significantly different ($p < 0.05$) in ELNs vs. paper-based notebooks (Figure 2). ELN submissions received an overall mean score in the *communication* category of 34.2 ± 3.4 (out of a possible 40 points), 29.2 ± 2.4 (out of a possible 32.0 points) in the *documentation* category, and 23.0 ± 1.8 (out of a possible 24.0 points) in the *presentation* category. In comparison, the paper-based lab notebooks received an overall mean score in the *communication* category of 25.9 ± 6.0 (out of a possible 40 points), 26.3 ±4.2 in the *documentation* category (out of a possible 32.0 points), and 18.7 ± 2.5 in the *presentation* category (out of a possible 24.0 points). Excerpts from a paper notebook and an electronic notebook are shown in Figures 3 and 4, respectively.

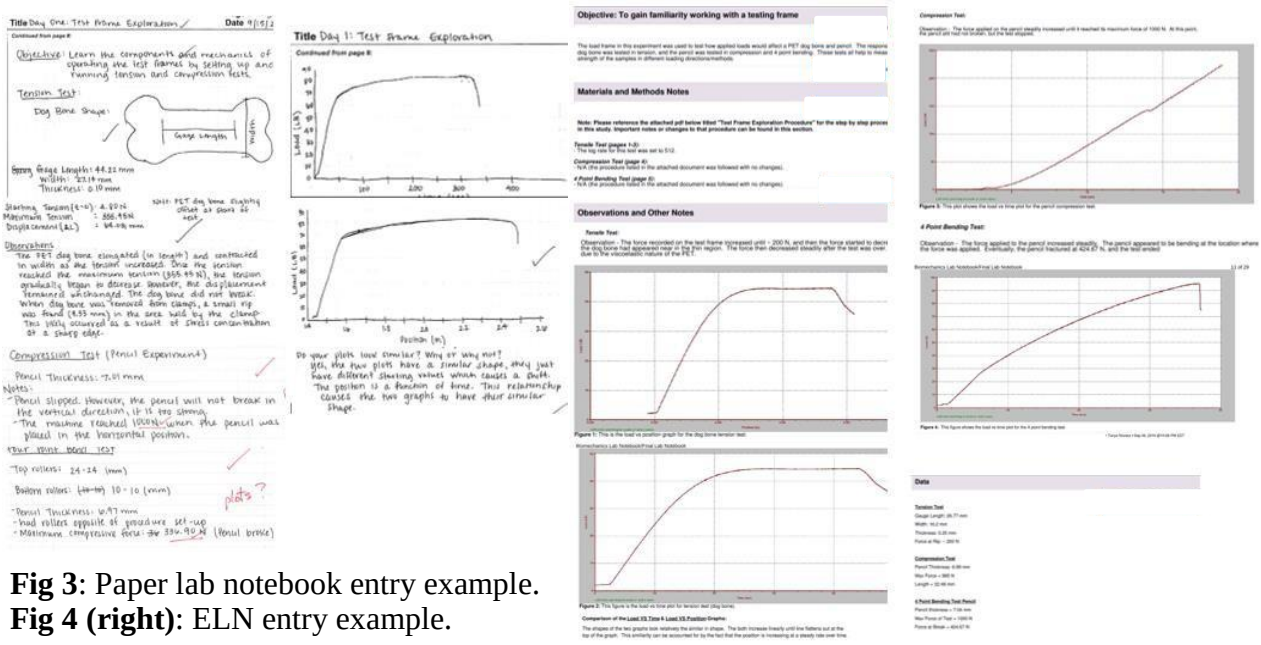

Fig 3: Paper lab notebook entry example.
Fig 4 (right): ELN entry example.

Discussion

It was observed that the electronic lab notebook (ELN) format may improve biomedical engineering students' quality of documentation and technical communication compared to those using the traditional paper-based laboratory notebook format. When comparing the scores between the two groups of students in the *communication* category, ELN student submissions more often described a clear and measureable objective, clearly communicated what was being completed in the laboratory session, used appropriate technical jargon, and restated the goal(s) of the experiment.

In the *documentation* category, students who used ELNs were more often able to summarize the lab methodology used, discuss their experimental observations, match their observations and discussions to the goal of the lab, and record an overall higher quality of documentation. In the *presentation* category, students using ELNs better organized their notebooks and more consistently documented all of their raw data compared to students using paper-based notebooks.

The electronic, cloud-based platform of ELNs offered several unique advantages over paper-based notebooks that may have contributed to improved communication, documentation and presentation. First, documenting in a paper notebook only allows for linear entry of documentation, whereas electronic notebooks allow students to re-visit, revise and address instructor feedback, as well as update and add to their notebooks non-linearly throughout their laboratory experience. This feature supports the increase in ELN scores in presentation and documentation especially, because students could re-order and insert information at a logical location and at later dates. Most students revisited their ELNs outside laboratory times to add extra experimental background notes and upload data plots and analyses they completed after the lab sessions. This extra detail and level of effort exerted outside of lab hours was typically uncommon while using paper-based notebook keeping. Also, because of the linear-entry documentation of paper-based notebooks, students could only be reasonably expected to address feedback and show improvements in future entries instead of revisiting and updating previous entries.

Another advantage of is ELNs is that videos, photos, PDFs, and other similar file formats can be uploaded to the notebook. Students therefore could video record and/or take photos of their experimental set-ups, procedures, etc. and quickly append to their ELN, which was more thorough and less time consuming compared to handwritten descriptions and drawings inherent to paper-based notebook keeping. Additionally, students could type more quickly than they could handwrite. More details could therefore be captured in ELNs in a shorter amount of time, compared to paper-based methods, allowing for more thorough and detailed communication and documentation of thoughts.

The selection of the rubric categories was intended to measure quality of documentation and technical communication. Current on-going studies include collection and analysis of student survey feedback regarding the students' perceived educational experience with electronic laboratory notebooks. In other future studies, it would be beneficial to develop a methodology to capture the aspects of lab notebooks that may be difficult to measure through the use of rubrics. For example, electronic lab notebooks have been discussed to assist in collaboration and accessibility [Guerrero 2016]. Considering these biomedical engineering students were working in teams during their biomechanics laboratory experience, assessing the effectiveness of electronic lab notebooks on collaboration may also yield useful information. ABET has also outlined for students to have the ability to work in a team, and so electronic lab notebooks may help students develop this skill.

Additionally, comparing visual communication skills in paper-based versus electronic lab notebooks would further address the effectiveness of electronic lab notebooks. Clarkson discussed the importance of incorporating written and visual communication skills in teaching technical communication [Clarkson 2016]. Lab notebooks require students to present a narrative of the lab as well as organize and present data. Considering students traditionally practice visual communication in writing a comprehensive technical report or giving an oral presentation, lab notebooks may also be a medium to help students develop visual technical communications [Clarkson 2016].

This study was conducted in a way to reduce factors that may influence results. The investigators assessed the ELN and paper-based notebooks using the same rubric (Table 2). However, there are some factors that were difficult to control. Some students may have taken a different biomedical engineering laboratory course prior to the biomechanics lab courses we selected for this study, and so these students may have improved documentation skills due to their experience. Factors like poor hand-writing and disorganization are minimized in ELNs, which may have skewed results in the *presentation* category. Additionally, formative feedback for students using ELNS was provided electronically. This form of feedback may have been more accessible to students and could also explain why student using ELNs showed significantly better communication, documentation and presentation. Lastly, the graduate teaching associates between the two courses chosen for this study were not the same, and so the quality of formative feedback provided to students may have influenced the skills assessed in the lab notebook.

Conclusions

On average, electronic lab notebook submissions earned higher documentation and technical communication rubric scores compared to paper based notebooks ($p < 0.05$). Scores indicated whether or not notebooks met, partially met, or did not meet each of twelve assessment criteria in the categories of *communication*, *documentation* and *presentation*. ELNs may therefore be an effective medium to engage engineering students in practicing and improving their ability to communicate effectively.

Based on the results, the authors are encouraged to continue use of ELNs in this and other laboratory or capstone courses, as well as expand the use of ELNs to contain additional student deliverables. For example, ELNs have the potential to create, contain, and grade lab assignments within its platform. This may allow the curriculum and its assignments to be contained and maintained in only one platform, allowing curricular activities to be streamlined and thus improve the experience for the student and the instructors.

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