A Review of Electronic Engineering Logbooks Throughout the Electrical Engineering Curriculum

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Abstract

Successful engineers must be well versed in communication skills, particularly with respect to written documentation in engineering logbooks. Such logs provide technical records that facilitate the day-to-day work of individual engineers, as well as enable continuity when projects are transferred to other engineers. Due to changes in technology and patent law, as well as the promise of simple archiving and sharing of technical work, many practicing engineers have moved away from traditional bound paper engineering notebooks and have embraced electronic documentation methods. This work details the experiences of junior electrical engineering faculty members implementing electronic engineering logbooks in their courses at the Milwaukee School of Engineering. While the current literature contains some discussion of electronic logbook usage in single courses, this paper takes a broader view by reviewing the use of electronic logbooks in courses that span all aspects of the electrical engineering undergraduate curriculum, from freshman to senior year. With this diverse set of courses, the lab assignments range from prescriptive step-by-step procedures to open-ended design projects. Each faculty member has been teaching for less than six years and joined academia with several years of industry experience. This work shares their experiences and observations on the advantages and disadvantages of electronic notebooks learned through implementation in their courses. Though this paper is primarily focused on electronic notebook usage in the electrical engineering program, the general observations are applicable to a broad range of engineering disciplines.

1 Introduction

Creating engineering documentation through an engineering logbook is a critical skill for engineering students. It provides a systematic way of cataloging their work and it encourages them to reflect on what they have learned and articulate it in a professional manner. It also prepares them for industry, where documentation is a key deliverable in development projects.

Bound, handwritten paper engineering logbooks were historically the staple tool of the practicing engineer in industry and, as a result, a norm for engineering students. These bound logbooks were simply the most efficient documentation method available. Even today, engineers can easily carry out calculations, sketch diagrams, and write down comments on their observations directly into the bound logbook, and the format allows them to rapidly switch between these activities [1]. This ease of documentation makes engineers more likely to carefully record their work in real time, including results that they discarded due to error or due to modifying their design. As a result the bound logbook tends to be viewed as a true personal working log that welcomes scratch work and back of the envelope estimates alongside more detailed, in depth analysis. The logbooks require no power source and are extremely portable. For students, the bound format allows all labs for a course to be kept together in one volume. This bound volume becomes part of the student's library at the conclusion of the course, with the information readily available for reference in later classes. Additionally, up until recently patent law was defined by a first to invent policy, where inventors needed to be able to prove when an idea was initially conceived in order to be awarded patents and successfully win infringement cases; handwritten logs written in indelible ink, with careful dating and signatures of the inventor and a witness were invaluable legal documents. In 2011, patent law moved to a "first to file" policy, where ownership of a patent now depends on who files the patent first [2]. As a result, for most engineering projects the logbook no longer carries a legal role.While bound paper logbooks served well as a natural documentation tool for many years, technological and patent law advances have paved the way for electronic documentation to replace the tried and true handwritten, bound logbook.

Electronic documentation has been made dramatically more practical and accessible due to recent advances in computing, especially the proliferation of tablet and stylus enabled computers [3], [4], and as a result has changed the way practicing engineers document their work. This trend has caught the interest of engineering educators. With a tablet and stylus, students can hand-write their documentation directly into their electronic log, just as they would in a bound paper notebook. In this regard, with the right hardware, electronic documentation can retain the benefits of bound logbooks while taking advantage of the inherent electronic format benefits. It is no wonder that electronic documentation now dominates industry, and training students on the importance of accurate, complete documentation of their work remains critical regardless of the medium.

In response to this trend, over the past decade educators have been studying the efficacy of electronic logbooks, [5], [6], [7], though typically within the narrow context of a single course [8], [9], [8], [6], [10]. The electronic logbook format has also opened the door to unique methods of assessing student learning through comprehensive electronic student work portfolios [11], [12]. Attention has also been paid to the practical aspects of moving to electronic documentation, such as using text [13], audio [14], and video [15] feedback on electronic submissions.

This paper describes how electronic engineering documentation has been embraced by the electrical engineering (EE) program at the Milwaukee School of Engineering (MSOE) across the curriculum. Until very recently, bound logbooks were used in most courses, but the majority of courses now utilize some form of electronic documentation. Some programming and digital logic courses represent a few early adopters. Three junior faculty have been engaged in this transition, and this paper documents their experiences in their courses. The paper is organized as follows: Section 2 provides an overview of each author's experience using electronic notebooks in the classes they teach and the type of documentation required for each class. Section 3 collects general observations and discusses the anecdotal pros and cons of using electronic documentation. The paper concludes in Section 4.

2 Lab Notebook Experiences

This section provides a brief description of how lecture and lab sections interact at our institution (section 2.1) and a personal narrative for each of the junior instructors (sections 2.2-2.4). The personal narratives provide a broad overview of their experiences using electronic lab notebooks in industry before joining the faculty at MSOE, and explains how electronic documentation is used in their courses. Table 1 provides a summary of the courses and type of documentation discussed.

Course	Level	Lab/Project	Submission Frequency
Linear Circuits - Steady State 1	Freshman	Lab	Weekly
Digital Logic I	Freshman	Project	Weekly
Digital Logic II	Freshman	Project	Weekly
Embedded Systems I	Freshman	Project	Weekly
Embedded Systems II	Sophomore	Project	Weekly
Object Oriented Programming	Sophomore	Project	Weekly
Analog Electronics I	Junior	Lab	Weekly
Analog Electronics II	Junior	Lab	Weekly
Electromagnetic Waves	Junior	Lab	Weekly
Digital System Design	Junior	Project	Weekly
Control Systems	Junior	Lab	Weekly
Design of Logic Systems	Junior	Project	Weekly
Antenna Theory	Senior	Project	Capstone report

Table 1: Summary of electronic notebook usage in courses taught by the authors in the electrical engineering program at MSOE.

2.1 MSOE Background

As an engineering education focused institution with strong industry connections, MSOE provides students with hands-on learning experiences. The academic year is divided into three ten-week terms, each with an additional week for final exams. Most EE courses include a lab component, where the lecture and lab together comprise one class section, and the two are tightly coupled. Faculty teach both the lecture and the lab sessions, without the aid of teaching assistants. As a result, faculty are on the front lines of setting documentation requirements as well as providing feedback and assessing outcomes.

2.2 Instructor 1

After finishing graduate school, I worked for two years at a not-for-profit Federally Funded Research and Development Center (FFRDC), performing applied research for several US government organizations. In this position I kept a bound, handwritten logbook that was primarily of personal use (was not required). Instead, most project documentation was done through electronic technical reports. In 2013, I transitioned into engineering education and joined the electrical engineering program at MSOE. This academic year marks my fifth year of teaching. For my first two years

I primarily used bound paper logbooks in my courses. This was typical of most courses at the time, and students were issued standard laptops (no stylus capability), which are not ideal for doing electronic documentation. In recent years, faculty and students have moved to combination laptop/tablet platforms with stylii that are better suited for such documentation. This technology change inspired me to modify the documentation requirements in my courses.

The courses I teach span the junior and senior levels and range from theory-intensive courses with no laboratory component, to courses with procedural-based labs investigating a physical law, to courses with open-ended design intensive labs. The documentation requirements are therefore different course to course, but in general focus on instilling proper technical documentation norms along with the technical work. Notebook entries follow a specific format. The first section is an introduction/background section with clearly articulated experiment objectives. The second section contains theoretical background calculations and/or design as appropriate. The third section then documents the results, including detailed measurement setup diagrams and justification of measurement methods used. It is important to note that no analysis is included in this section. Finally, the last section is the analysis of results, which contains any calculations and plots, and includes discussion of the results. A key goal is forcing students to separate the data collection from the analysis. Finally, for each lab experiment students submit, separate from their lab notebook, a brief typed concluding summary is required that includes the following:

1. Context — provide background justifying why the experiment was undertaken,
2. Purpose — what they wished to accomplish with the lab (purpose must be *testable*!),
3. Key Data — summary of the most important data from the experiment,
4. Take-away — states their conclusion based on the data and what the key outcome was.

A major emphasis is placed on getting students to reflect on the meaning of their results and how to communicate them in a concise but complete manner; in short, developing the professional habits of a practicing engineer. The following briefly summarizes the documentation requirements in several of my courses.

Analog Electronics I and Analog Electronics II are required junior-level core EE courses in our program. In addition to providing students with a firm background in electronics, the courses are also intentionally configured to provide students with substantial design experiences. Nearly every lab involves students performing design work, which can range from determining component values for a standard circuit to open-ended design exercises where students must design a complex multistage circuit to meet specifications. The documentation is significant, involving developing a conceptual idea through the design and simulation phases, up through measuring performance, and then finally analyzing whether the designs meet specifications. In my Analog Electronics courses, I select two labs, usually the first lab and then a lab about midway through the course, and turn lab submissions back to students without a grade but with detailed feedback. Students are then allowed to edit their lab submission and resubmit for a no-penalty regrade. Since the notebooks are electronic, this task only requires students to modify an existing document, rather than recreate the submission. The ability to resubmit has had noticeable effects. Namely, students are more motivated to read and consider the feedback and make changes to their report, since their grade has not yet been assigned and they can still change it. Making changes to the same lab for which feedback has been provided seems to be, anecdotally, more effective for student learning compared to applying the feedback to the next, different lab exercise. Finally, this method promotes a quasi-mastery attitude, which reinforces that lab documentation requires practice and should be revised until it is clear, complete, and accurate.

Electromagnetic Waves is another required junior-level core EE course. This is the second course in a two-course electromagnetics sequence, and focuses mainly on dynamic electromagnetics, such as induction, transmission lines, and antennas. The lab experience in this course has no design component but instead is focused on an exploratory mindset where experiments involve observations and analysis of measurements. Weekly experiments are documented in the students' lab notebooks except for the conclusion section, which is submitted as a separate document.

Antenna Theory and Wireless Applications is a senior-level technical elective that builds on the required electromagnetics courses and covers basic electromagnetic theory up through practical antenna implementation and wireless systems. There is no lab to this course, but students keep an electronic log over the course of a simulation project that they complete outside of class. The log documents the simulation of a Yagi-Uda antenna, where students build the model progressively and use simulation to carry out an open-ended exploration of the fields to develop intuition for how the antenna works. While there is no design component, focus is instead placed on careful documentation and interpretation of the simulation results.

2.3 Instructor 2

I began working at MSOE in 2016. Prior to earning my Ph.D. in Electrical Engineering, I worked in the aerospace industry. I had various tasks from test to design, all of which included various forms of documentation. I was not required to have an official (bound or electronic) notebook, but I did have to provide design details through reports and presentations created electronically. At MSOE, I teach the digital logic sequence, which consists of two courses in the freshman year and a third course in the junior year. I also teach control systems, which students take their junior year. I have mainly required electronic notebooks from my students while teaching at MSOE.

The electronic notebooks in my courses are generally in the form of reports that have an overview, description, results, and conclusion. The overview shows that the students can put the purpose of the laboratory experiment into their own words. The description provides the actions taken and design details required to complete the lab. The results show simulation or measured data with discussion on what these results show and why the results are valid. Lastly, the conclusion discusses insight gained from the experiment, and I encourage the students to include lessons learned to reflect on how the lab went.

In Digital Logic I (freshmen), the students build circuits with 7400 series integrated circuits as well as design their circuits via a hardware description language (HDL). Once their design is functional, they must demonstrate it to me. After the demonstration has been completed, I require that the students submit an informal report that documents their design and results, which are submitted electronically to MSOE's learning management system (LMS). The reports include a design description, supporting work, and any relevant screenshots. I also consider commenting the HDL code to be a critical portion of the students' electronic documentation. Digital Logic II (freshmen) focuses on HDL development rather than physical circuit building, which leads to the reports having a more structured format with a higher expectation on HDL commenting.

In Digital System Design (juniors), the students are expected to write an overview, description, results, and conclusion within one page that explains what their design is supposed to do, why, and how they achieved their goal. It is recommended to the students to be concise in the first portion of the report because they are required to extensively comment their HDL code. In this course, good code commenting practice is one of the key factors of the students' reports.

In Control Systems (juniors), the students work with a partner and together are expected to provide an overview, a description that walks through their design process that includes their results obtained throughout lab, and a conclusion. The majority of the lab reports completed for my control systems course are informal and are meant to allow the students to gain experience documenting their design process, collecting data, and analyzing the data. There is one formal report due in the course that the students submit individually, in which the students must follow a strict outline. However, it still follows the main structure they have been using prior in the term. In future offerings of this course, I plan to have informal reports focus on specific documentation elements that lead up to the formal report. This will give the students guidance when they prepare their formal report.

2.4 Instructor 3

After finishing my undergraduate degree, I worked for a software company where I supported customers by helping them maintain and configure our software. As a company, we used a homegrown program to document nearly all functions of the company, including customer support, product development, and quality assurance. I then attended graduate school and earned a Ph.D. in electrical engineering. After graduation, I accepted a faculty position at MSOE and I am currently in my third year of teaching. I teach courses in all four years of MSOE's EE undergraduate curriculum, though I only teach classes with laboratory portions in the first three years. These courses include Linear Circuits, Control Systems, Introduction to Embedded Systems, Embedded Systems (separate classes for sophomores and junior transfer students), Object Oriented Programming, and Design of Logic Systems (junior transfer students). From the start of my career at MSOE I have exclusively used electronic notebooks in my classes.

The primary goal of the lab notebook submissions in my classes is to give students the experience of producing the types of engineering documentation that are required of them in the work place and to provide a practical way for the students to apply the knowledge learned during lecture. As it relates to electronic lab notebooks, the classes I teach can be divided into two broad categories. The first category is the set of classes that have weekly projects that are assigned and verified for correct functionality during a lab period. These classes fit into the programming and digital logic side of our EE curriculum. The other category of classes are those that require a traditional lab experiment. These classes require special lab equipment to perform the experiment. The differences in assignment type lead to different requirements in lab notebooks.

In classes where lab assignments take the form of weekly projects (the software focused and digital logic classes), the lab notebook submissions are primarily descriptive documentation of the product being delivered and there are generally no real experimental results to be described. The lab notebook submission that goes along with each assignment mimics, in a small way, the type of documentation that might be required with a completed software product in industry. Depending on the assignment and class, the lab notebook submission includes a text description of the project (purpose, design procedure, and conclusion/lessons learned), flowcharts describing high-level algorithms, screen shots, and wiring diagrams describing the circuit required for proper functionality. All lab reports of this type also include the student's source code, which is verified to ensure that the student used the required techniques, and feedback is given to encourage good coding practices.

For classes that require a traditional lab experiment each week, the primary goal of the lab notebook is to teach students how to document a lab experiment. These lab notebook submissions usually include sections on background theory, experiment design, data, results, and conclusions. The required information in each submission becomes more extensive as the students progress through their career. Therefore, the report for a freshman class will require significantly less information than a report for a junior or senior level class.

Regardless of the type of class, all lab submissions are submitted electronically as individual assignments to our institutions LMS. The assignments are graded in the LMS, where my feedback and the final grade are available for review by the student at any time.

3 General Observations

While the previous section provides overviews of electronic notebook usage in the experience of three faculty members, this section represents the collective analysis of these experiences (section 3.1). The benefits and drawbacks of the electronic notebooks are considered in the context of faculty usage (impact on grading, for example), assignment time frames, and student experience (anecdotal, through observations by faculty members). A summary of the most prominent advantages and disadvantages is shown in Table 2. This section also includes a brief discussion of our different grading methods (section 3.2).

Advantages	Disadvantages
Accessibility	Not all students have stylus-enabled tablets
Electronic grading	Cheating is hard to detect
Unique feedback and revision techniques	Entering equations can be difficult
Ease of storage/backup/sharing	
Consistent with industry practice	

Table 2: Main advantages and disadvantages of electronic logbooks as observed by faculty.

3.1 Advantages & Disadvantages

The following discussion is drawn from the personal experience of all three faculty members, and in this regard is not necessarily comprehensive. The central theme of the advantages of the electronic notebook is ease of storage, access, and backup. The disadvantages tend to stem around the unfamiliarity of using electronic logging in an informal manner and the over-dependency on technology.

There are many benefits regarding the use of electronic logbooks. By having an electronic submission, students will still have access to their assignment while an instructor grades the assignments.

If an LMS is used for submissions, most can be configured to set due dates which has two main benefits: students get a reminder that an assignment is due automatically through the LMS and the LMS can flag late submissions. Electronically submitting assignments also provides students the ability to submit their work on their own time when the assignment is complete, instead of having to remember to bring it to class. Due dates can also be decoupled from lecture or lab meeting times, or even from normal campus hours (one of the authors sometimes schedules midnight due dates). No unattended, asynchronous “drop boxes” for student work are required, which can lead to student work being missed and also poses risks to student privacy. Returning assignments electronically allows the professor to avoid using valuable class time to hand back assignments, and aids in providing timely response to students. By removing the handling of papers among many different people during flu and cold season, also improves overall productivity of faculty by increasing their chances to stay healthy.

When students work in groups, a collaborative report in a paper notebook can be quite difficult. With electronic submissions, students (anecdotally) can easily share their documentation with one another, and can even collaborate on shared cloud platforms where appropriate. Measurements, especially screen shots from equipment, and simulation results can be inserted directly into their electronic logbook without having to physically cut and paste these into a bound paper log.

Grading electronically also has many different benefits. Instructors are able to explore new educational methods to help students improve their documentation skills. Students have easy access to past material and graded assignments, increasing their ability to leverage feedback from the instructor. Also, instructors are no longer required to take piles of paper home to grade, but instead just their laptop/tablet. Grading does tend to go more quickly electronically, whether feedback is typed or handwritten using a stylus on a touchscreen device. The portability of the electronic logbook also makes it more convenient and accessible to grade nearly anywhere compared to bulky paper logbooks. Lastly, because the feedback is preserved, faculty can adjust their grading depending on if previously provided feedback for an error was addressed or if it was ignored and the error was repeated.

There are a few disadvantages that the authors have noted. For mathematically involved courses (circuits vs C-programming), students do not enjoy typing equations into reports. As mentioned previously, the LMS can be configured to have a due date, which is provided to the student, yet counter-intuitively students sometimes seem *more* likely to submit late work electronically. Students also have a difficult time thinking of informal electronic logbooks as truly informal, since until this point, if they were creating an electronic document it was a formal report. For example, there have been instances where students approach every lab entry as though it is a formal report, creating a lot of work for the student and depriving them of developing both types of documentation skills (formal vs. informal). On a pragmatic note, mention must unfortunately be included here of the fact that cheating is substantially easier to do in electronic format, where in this case the easy sharing of the logbooks becomes a downside. In particular, in cases where the logbooks are typed and utilize computer generated drawings, the cheating becomes difficult to detect since there is no handwriting to differentiate student work. Finally, successful usage of electronic notebooks relies heavily on technology and instructors must keep in mind that we are not at a point in time where all students have a stylus or enabled PC. Those students using a traditional laptop (without stylus capability) will see somewhat higher barriers to documenting their work in real-time in lab, since they must type text and generate graphics using a keyboard and mouse. As a work-around this issue, one author encourages students to hand write and then scan math equations and diagrams into their electronic logbook to save time and effort. Nevertheless, as more students obtain tablet or stylus enabled computers (combined these platforms show a projected growth of 46% worldwide over next four years [16]), this issue will subside dramatically.

3.2 Grading Practices with Electronic Notebooks

Assessing electronic notebooks opens up unique grading possibilities. Each of the three instructors utilizes a different workflow for providing feedback and assigning a grade. On one end of the spectrum, one instructor grades and provides feedback entirely on the computer using a tablet and stylus, by handwriting comments onto the students electronic notebook entry. On the other end of the spectrum, one instructor prints out the labs and provides feedback by hand in pen on the paper and turns these graded lab notebook entries back to the students; essentially leaving the electronic aspect behind once the lab notebook entry is submitted. Finally, the third instructor is somewhere in between, providing feedback via typed text and rubrics fully within the learning management system, directly on the students electronic submission. There is flexibility allowed via the electronic nature of the submissions, and there are instances when one method may be preferred over another for a particular type of assignment, or may also depend on the technology available to the faculty.

4 Conclusion

Engineering education is catching up to industry in the usage of electronic documentation, where the classic bound, paper engineering logbook is increasingly being put aside in favor of electronic documentation. This trend is largely driven by changes in portable computing technology (and cost) and recent changes in patent law. At MSOE the electrical engineering faculty have embraced this trend across the curriculum, and have seen mostly beneficial impacts.

On the administrative side, faculty have appreciated the due date flexibility, timestamping of submissions, and easy sharing and backup of a student's work. The format allows for simple documentation of measurement screen captures, simulations, and data plots without wasting paper and requiring glueing into bound logbooks. New grading methods are possible, where feedback can be given electronically directly on student work, and assignments can be collected and returned to students outside of class meetings. The reduction in bulk of carrying around a stack of logbooks is also a major benefit. Faculty have observed some drawbacks, however. Students without access to a tablet have a more difficult time documenting their work electronically, especially when entering equations into their reports. Students can also mistake the electronic format as more formal than a bound paper logbook, though as electronic documentation becomes commonplace that may go away over time. Finally, the electronic format does lower the barrier for student cheating, but we have not noticed a difference in the number of academic integrity violations for electronic notebooks compared to paper-only assignments.

Overall the electronic documentation transition has been well received by both faculty and students, and is a closer model of the type of documentation students will encounter in industry. With these positive experiences, faculty at MSOE are continuing to experiment with electronic documentation and future work seeks to assess how this new format is impacting student learning and their development of documentation skills.

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