

Tablets for Timely Design Documentation

David G. Meyer <meyer@purdue.edu>
Mark C. Johnson <mcjohnso@purdue.edu>
Cordelia M. Brown <brown83@purdue.edu>
Purdue University
School of Electrical & Computer Engineering
West Lafayette, Indiana 47907

Abstract

One of the biggest challenges we have experienced in supervising digital systems senior design projects is the quality and completeness of the individual lab notebooks. Of the five outcomes we continuously track for this capstone course, the lab notebooks have consistently received the lowest quantitative scores. A significant improvement was achieved three years ago when we transitioned from “carbon paper and pen” notebooks to on-line (HTML) notebooks. Many 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 primary drawback has been the need for students to be in front of a networked computer to make lab notebook entries; consequently, the notebook updates still tended to be done in “spurts” (typically “after the fact”) rather than in “real time”. Project work (and inspiration), in fact, does not always occur in a lab setting, where networked computers are readily available, nor does it occur when all team members are working in the same physical location. Our hypothesis is that equipping each project team with wireless Tablet PCs should not only significantly improve the spontaneity (and regularity) with which the on-line lab notebooks are updated, but also facilitate collaboration among team members working on the design project at different locations. An HP Technology for Teaching Grant has provided a critical mass of Tablet PCs to test this hypothesis. A description of how the equipment provided is being utilized, along with a discussion of the preliminary results obtained, is presented in this paper.

Introduction

In most team-oriented capstone design courses, creation and maintenance of individual laboratory notebooks (or design journals) is an important key to successful project completion. Unfortunately, this very necessary ingredient of successful engineering design is also the one for which it is most difficult to garner enthusiasm among students. Typically, students would rather “just work on the project” than document the process; consequently, procrastination sets in and the engineering design process utilized is often documented well after the fact (days, even weeks), if at all. This dilemma is documented in the following self-evaluation, written by the author six years ago.

Individual lab notebooks varied greatly in quality – some of them were simply “narratives” of group meetings, while others appeared to be transcribed “after the fact”. We attempted to address these issues by evaluating each student’s lab notebook tear-out sheets several times throughout the semester (on a total of four

different occasions). While this rather significant effort on the our part lead to notable improvements in the lab notebooks relative to previous offerings, there is still room for improvement — especially for team members charged with software development, who generally kept the “worst” notebooks. The fundamental problem appears to be getting students to: (a) appreciate the value of a good lab notebook, and (b) take it seriously.¹

While laboratory notebooks have traditionally been pen and pencil based, a recent trend has been the development of electronic lab notebooks (ELNs). Use of an ELN facilitates ready sharing of project development process and status among teammates, as well as with the instructional staff. Advantages of an ELN over a paper notebook include: (a) ability to share it among team members; (b) remote access capability; (c) ability to back it up so that it cannot be misplaced, lost, or accidentally destroyed; (d) ease with which computer files, plots, etc. can be incorporated; (e) ability to electronically search; (f) ability to include audio/video clips; and (g) ability to include hyperlinks to other information (e.g., device data sheets).²

Electronic notebooks are generating significant interest, as evidenced by a wide variety of commercial and “freeware” products currently available, formation of the Collaborative Electronic Notebook Systems Association, and the series of Electronic Lab Notebook Conferences.³ Commercial products currently available include: LabTrack⁴, NoteBookMaker⁵, Infotrieve⁶, Nexxis qELN⁷, Contur ELN⁸, and idbs E-Workbook⁹. A noteworthy “freeware” tool is ORNL ELN². A chart comparing features of these products is provided in Figure 1.

There are several challenges associated with ELN use, however. A key issue is notebook security: access to a particular lab notebook, its contents, and authentication of entries are fundamental issues that must be addressed. To facilitate non-tamperability of entries, the ELN should automatically date and digitally sign each entry, then append that entry to the last page of the notebook. Notarization and witnessing functions also need to be provided. Yet another challenge that applies to ELNs shared by project team members is the need to be in front of a networked computer in order to update entries.

Before discussing ELN considerations further and the motivation for use of Tablet PCs, specific details about the target capstone design course along with its intended outcomes and how they are assessed is in order.

Capstone Design Course Specifics

The capstone senior design course that is the subject of this study has five outcomes that are quantitatively assessed:

1. An ability to apply knowledge obtained in earlier coursework and to obtain new knowledge necessary to design and test a system, component, or process to meet desired needs.
2. An understanding of the engineering design process.
3. An ability to function on a multidisciplinary team.
4. An awareness of professional and ethical responsibility.
5. An ability to communicate effectively, in both oral and written form.

This course is advertised as “a structured approach to the development and integration of embedded microcontroller hardware and software that provides senior-level students with significant design experience applying microcontrollers to a wide range of embedded systems (e.g., instrumentation, process control, telecommunication, intelligent devices, etc.).” The fundamental course objective is to provide practical experience developing integrated hardware and software for an embedded microcontroller system in an environment that models one which students will most likely encounter in industry.¹⁰

The basic project-related constraints are that the design must utilize a microcontroller, digital signal processor, or a programmable system-on-chip, meaningfully incorporate several “standard” interfaces (e.g., I²C, SPI, TCP/IP, RF, IR, Bluetooth, Zigbee, etc.), be implemented on a custom-designed printed circuit board, be neatly (and appropriately) packaged, be of personal interest to at least two team members, and (last but not least) be *tractable*. To this end, each team of four students prepares and submits a project proposal (in “draft” and then “final” form, following an initial review). Included in this proposal are five, student-specified project success criteria by which the system functionality will be judged (there are five additional success criteria that are common to all projects, covering deliverables such as the schematic, the bill of materials, the printed circuit board layout, the product packaging, and system integration).

Outcomes 1 and 4 are quantitatively assessed using a series of four *design component* and four *professional component* written reports (that serve as the precursor of corresponding sections in the final written report). Implementation of this strategy requires a “fixed” team size of four members and a corresponding class enrollment that is an integer multiple of four. Here, each team member is required to pick one topic from each set to individually research and produce a formal written report, complete with references. Together, the two reports constitute a significant portion of each student’s grade.

The design component reports are as follows:

1. Packaging Specifications and Design
2. Schematic and Hardware Design Narrative/Theory of Operation
3. Printed Circuit Board Layout
4. Firmware Listing and Software Narrative

The professional component reports are as follows:

1. Design Constraint Analysis and Component Selection Rationale
2. Patent Liability Analysis
3. Reliability and Safety Analysis
4. Social/Political/Environmental Product Lifecycle Impact Analysis

For Outcome 2 (“understanding of the engineering design process”), multiple evaluations of the individual lab notebooks provide a meaningful quantitative measure of successful demonstration. The breakthrough here was to create group accounts and team websites that hosted each member’s on-line laboratory notebook. Adoption of this approach allowed the course staff to conveniently check on team progress as well as individual contributions. Further, the HTML web-based approach allowed students to include hyperlinks in their notebook entries to photos of

prototyping setups, source code for testing various interfaces, video demos of project specific success criteria fulfillment, PDFs of data sheets used in the design, etc. The instrument used to evaluate lab notebooks is shown in Table 1.

For Outcome 3 (“ability to function on a multidisciplinary team”), the project success criteria provide a meaningful quantitative measure of completion. As part of the final presentation, each team prepares video clips that demonstrate success criteria satisfaction (these videos are also posted on the team web sites). Upon review, the course staff assigns a score based on an analysis of how thoroughly the success criteria have been met. Finally, demonstration of Outcome 5 (“ability to communicate effectively, in both oral and written form”) is based on the Design Review, the Final Presentation, and the Final Report.

For each of these course outcomes, grading rubrics have been developed and iteratively refined (an example is provided in Table 1).^{11,12} The minimum passing threshold established for each course outcome is 60%. In order to receive a passing grade for the class, each student must successfully demonstrate all five course outcomes.

Preliminary Results

Cohort averages for each of the five course outcomes, spanning Spring 2005 through Fall 2007, are plotted in Figure 2. The six-semester averages for each outcome are depicted in Figure 3. Effective Spring 2005, a transition was made from pen and paper lab notebooks to on-line (HTML) lab notebooks. During the Fall 2007 course offering, use of Tablet PCs was introduced. Each team of four students was issued two Tablet PCs, for the stated purpose of improving the quality of the lab notebooks. Our hypothesis was that equipping each project team with wireless Tablet PCs should not only significantly improve the spontaneity (and regularity) with which the on-line lab notebooks were updated, but also facilitate collaboration among team members working on the design project at different locations.

In practice, the Tablet PCs were used just as much for other course-related activities (such as writing reports and giving presentations) as for maintaining lab notebooks. Other uses of the Tablet PCs identified by students in the exit survey included: code development and debugging, on-line research, video editing, and remote login to other development hosts. With this in mind, it is interesting to compare the Fall 2007 cohort averages of Outcome 1 (professional component report), Outcome 2 (laboratory notebook), Outcome 4 (design component report) and Outcome 5 (technical communication skills) with the cohort averages for these outcomes spanning the previous five course offerings. Each of these appeared to notably improve, relative to the introduction of Tablet PCs in the course. Referring to Figure 3, the six-semester averages for Outcomes 1, 2, 4, and 5 are 77.0%, 77.6%, 77.3%, and 83.3%, respectively. Referring back to Figure 2, the cohort averages for these outcomes improved to 82.9%, 86.5%, 82.3%, and 88.0%, respectively, during the Fall 2007 offering. Note that Outcome 3, as a measure of overall project functionality (based on satisfaction of each team’s project-specific success criteria), does not necessarily correlate with the other quantitative measures. This is because a team can potentially do everything else well (good notebooks, good reports, good presentations, etc.), yet receive a below-average score for Outcome 3 due to an unpredictable event beyond the team’s control

(e.g., an unresolved hardware/software bug). For Fall 2007, the cohort average for this outcome (88.6%) was fairly close to the long-term average of 89.6%.

The Likert-scale survey results, shown in Table 2, provide insight on the perceived effectiveness of Tablet PC availability toward meeting our stated goal of improving the laboratory notebooks. Here, only about 30% of the students indicated that the availability of Tablet PCs helped them improve the quality of their notebook and/or the timeliness of their updates. Based on responses to questions 3 and 4, the impact of allocating only two Tablet PCs per four-person team was unclear. A potentially confounding issue, however – based on responses to questions 7 and 8 – appears to be the HTML format utilized: over half the respondents indicated that this was the primary factor that hindered their ability to maintain their laboratory notebooks. Correspondingly, a similar majority indicated that the availability of a commercial ELN software package would significantly enhance their ability to maintain a quality lab notebook. It will be interesting to see how this plays out in future trials.

Summary and Future Work

While our initial hypothesis (of improving timeliness of lab notebook entry) is yet to be demonstrated, unanticipated “side-benefits” were realized in the form of improved cohort averages for four of the five course outcomes. As described above, this lack of “buy-in” appears to be more of a function of the use of raw HTML-format for the laboratory notebooks, and therefore independent of Tablet PC availability. We will explore this effect by continuing our use of HTML during the current offering (Spring 2008), and then switch to a commercial ELN software package effective Fall 2008. We will then conduct two successive trials (Fall 2008 and Spring 2009) using an ELN package, and compare the results of those trials with the HTML notebook trials. This should enable us to decouple the software/formatting issues associated with the lab notebooks from the availability of Tablet PCs.

Acknowledgement

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	LABTrack	NoteBookMaker	Contur ELN	Nexxis qELN	Infotrieve	idbs E-Workbook	ORNL ELN	Wiki HTML	HTML
Client not required	*			*			*	*	*
HTML coding free	*	*	*	*	*	*			
HTML coding reduced	*	*	*	*	*	*	*	*	
Secure	*	*	*	*	*	*	*	*	*
21 CFR part11 compliant	*	*	*	*	*	*	*		
Notebook Searchable	*	*	*	*	*	*	*	*	
Database Searchable	*		*	*	*				
Supports Importing	*	*	*	*	*	*	*	*	
Visible imports	*	*	*	*	*	*	*		
Editable imports	*		*		*				
Auto notifications	*		*	*	*				
Online support	*	*	*	*	*	*	*		
Phone Support	*	*	*	*	*	*			
Technician support	*	*		*	*	*			

Figure 1. ELN Feature Comparison Chart.

Table 1. Lab notebook evaluation instrument.

Evaluation:

Component/Criterion	Score	Multiplier	Points
Level of technical detail – enough detail should be included for others to reproduce your work	0 1 2 3 4 5 6 7 8 9 10	X 1	
Pictures, drawings and diagrams – should be included where appropriate, very large images should be linked.	0 1 2 3 4 5 6 7 8 9 10	X 1	
Clarity – what you wrote should be readily understandable to one “skilled in the art” – if course staff can’t understand, it isn’t clear.	0 1 2 3 4 5 6 7 8 9 10	X 1	
Appropriateness of content – lab notebook should not be a “blog” (i.e., not be a log of time spent in class or what you ate at a meeting, etc.)	0 1 2 3 4 5 6 7 8 9 10	X 1	
Update record – daily entries should be made <i>as work is done</i> (not days “after the fact”), and should reflect steady, consistent progress	0 1 2 3 4 5 6 7 8 9 10	X 2	
Weekly summaries – weekly entries should be a concise summary of the major accomplishments for the preceding Sunday – Saturday period	0 1 2 3 4 5 6 7 8 9 10	X 1	
Formatting – must use global style-sheet and prescribed page layout; also, use links to pictures, code listings, data sheets, scanned images, etc.	0 1 2 3 4 5 6 7 8 9 10	X 1	
Technical Writing Style – writing style should be professional, concise, and inclusive as well as employ good grammar, sentence structure, etc.	0 1 2 3 4 5 6 7 8 9 10	X 2	
		TOTAL	

Scoring:

9-10	<i>Excellent – among the very best notebooks completed this semester</i>
7-8	<i>Good – all requirements were amply satisfied</i>
5-6	<i>Average – some areas for improvement, but all basic requirements were satisfied</i>
3-4	<i>Below average – some basic requirements were not satisfied</i>
1-2	<i>Poor – very few of the requirements were satisfied</i>

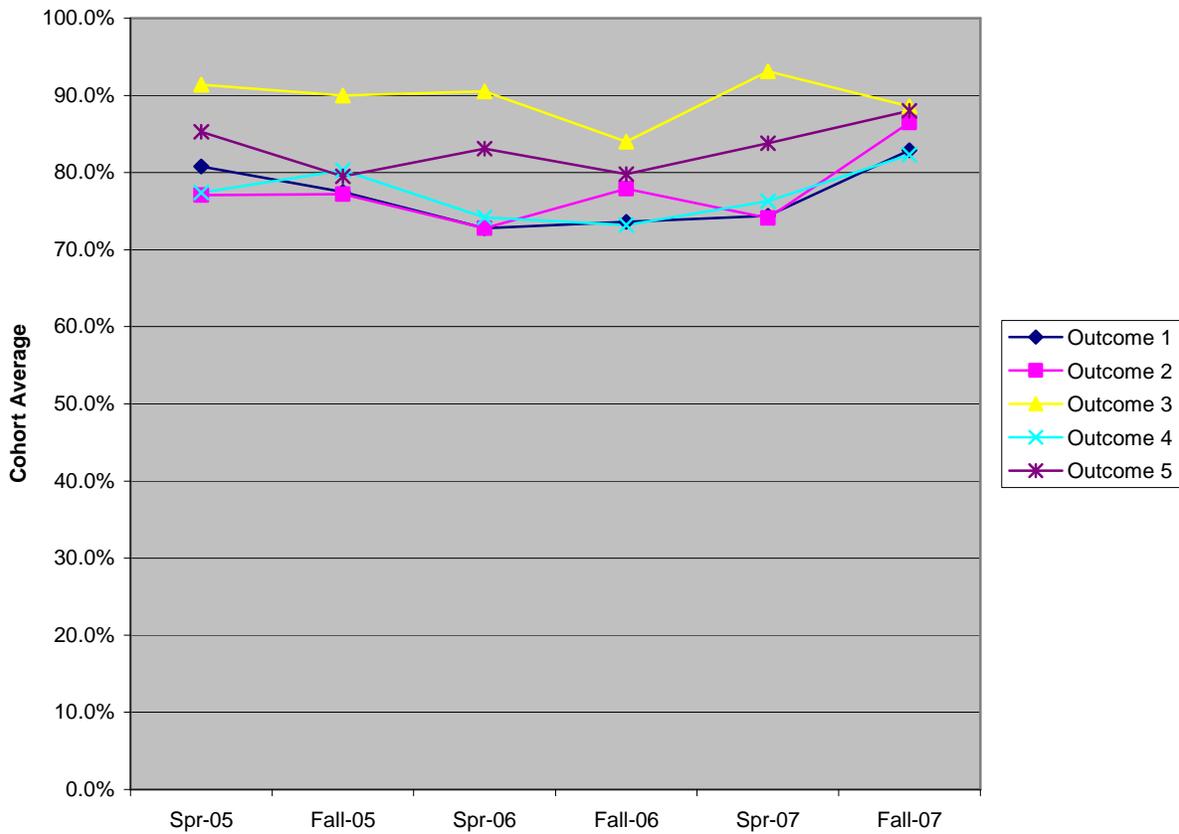


Figure 2. Capstone design outcome assessment cohort averages, Spring 2005 – Fall 2007. Outcome 1 is the professional component report, Outcome 2 is the laboratory notebook (final evaluation), Outcome 3 is the project success criteria satisfaction, Outcome 4 is the design component report, and Outcome 5 is oral/written communication skills (average of design review, final presentation, and final report scores).

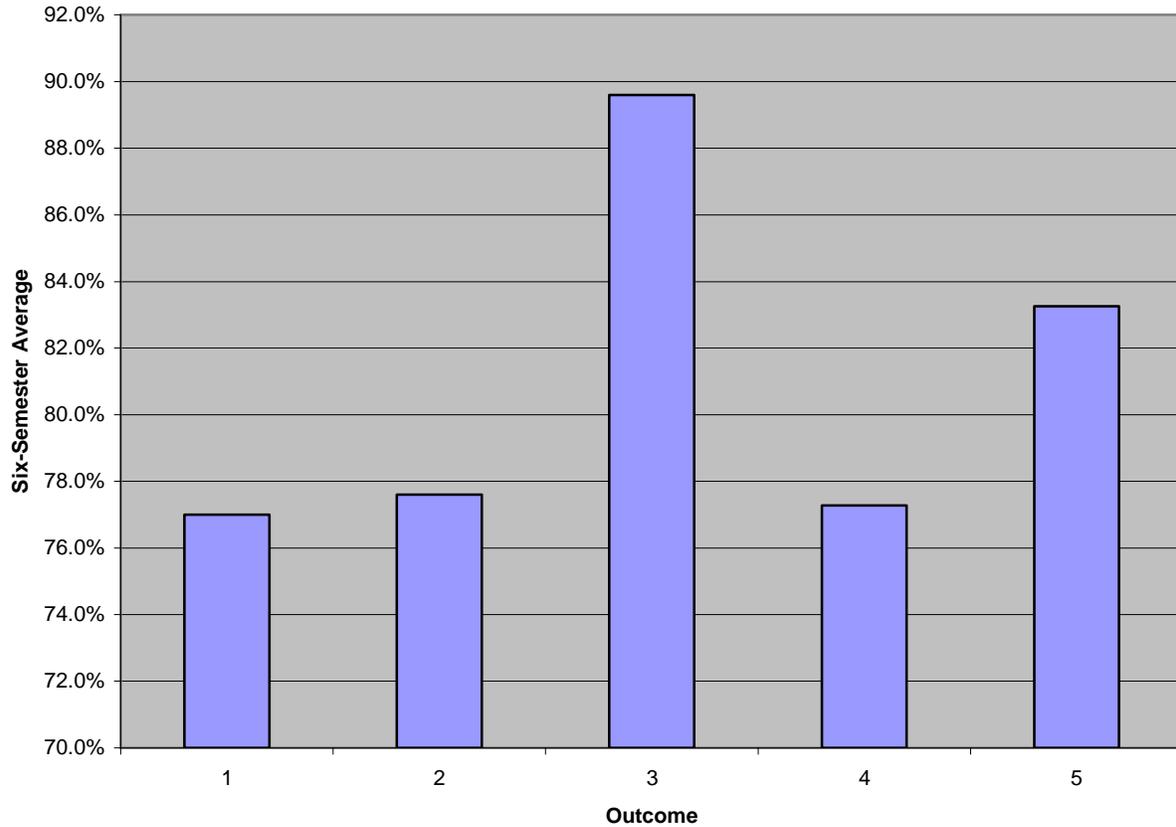


Figure 3. Scores for each outcome averaged over six semesters (Spring 2005 – Fall 2007). Outcome 1 is the professional component report, Outcome 2 is the laboratory notebook (final evaluation), Outcome 3 is the project success criteria satisfaction, Outcome 4 is the design component report, and Outcome 5 is oral/written communication skills (average of design review, final presentation, and final report scores).

Table 2. End-of-semester survey results (N=26).

<i>Question</i>	<i>SA</i>	<i>A</i>	<i>N</i>	<i>D</i>	<i>SD</i>
1. The availability of Tablet PCs positively influenced my ability to create a quality laboratory notebook for our team's design project.	1	7	7	8	3
2. The availability of Tablet PCs enabled me to update my laboratory notebook in a more timely fashion than would have otherwise been possible.	1	6	5	11	4
3. The allocation of <i>two</i> Tablet PCs per four-person team was sufficient for the purposes of this course.	2	14	3	2	3
4. The allocation of <i>only two</i> Tablet PCs per four-person team was <i>not</i> sufficient to have an impact on the quality of my laboratory notebook.	4	7	5	10	0
5. The assignment of a <i>single</i> Tablet PC per team (instead of two or more) <i>would have been</i> sufficient for the purposes of this course.	0	4	2	12	8
6. I used features unique to Tablet PCs in maintaining my lab notebook (e.g., digital ink).	0	6	6	6	8
7. The HTML-format laboratory notebook format allowed me to efficiently and effectively update/maintain my laboratory notebook.	2	5	5	5	9
8. The HTML-format laboratory notebook was cumbersome to use and hindered my ability to update my notebook in a timely fashion.	9	4	6	5	2
9. The availability of a commercial electronic notebook software package (e.g., <i>LabTrack</i>) would have significantly enhanced my ability to maintain a quality laboratory notebook.	5	9	9	1	2