Do Students Benefit? Writing-to-Learn in a Digital Design Laboratory Course

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Abstract - Communication instruction in engineering education has been formally integrated in numerous engineering programs, as industry and ABET increasingly require oral and written skills for engineering professionals. As engineering programs have adapted to these requirements, the need to understand the benefits of communication instruction to students while they are learning course content is paramount. This paper focuses on the “discipline-specific” method for teaching communication skills and addresses whether or not students learn the discipline-specific material more fully when they are required to write about that material. Data for this research comes from a sophomore-level communication-intensive digital design laboratory course. To assess retention, student answers to a specific final exam question are analyzed over three semesters. During these semesters, different writing assignments were associated with the tested subject matter. The results of this study speak directly to content-driven communication instruction and test performance.

Index Terms - technical writing, Writing Across the Curriculum, Writing in the Disciplines, knowledge retention.

INTRODUCTION

Since the mid-1990s, the School of Electrical and Computer Engineering (ECE) at the Georgia Institute of Technology has placed increasing emphasis upon teaching its majors communication skills appropriate to their discipline. Beginning in 2000 the School of ECE began developing its own in-house Undergraduate Professional Communications Program (UPCP). Since then, efforts have focused on defining the goals and objectives of the program, on integrating communication skills throughout the ECE curriculum, and on improving assessment methods.

The main objective of the UPCP is to ensure that all undergraduate students who receive degrees in electrical and computer engineering can communicate effectively (in both oral and written form). Increasing emphasis on written, oral, and visual communication is the result of several factors, including those outlined below:

- ABET’s EC 2000 requirement that competence in written and oral communication must be demonstrated by each engineering undergraduate (Section I.C.3.g.).
- Feedback from industry and alumni that explicitly identifies communication skills as being among the most important factors in both initial hiring and future career growth.
- Growing awareness within the School of ECE of the need for communication skills in a workplace increasingly reliant upon communication technology.

For the past four years (2000-04), the UPC Program has gone through several iterations. In an attempt to find ways to meet the ABET EC 2000 requirement, Georgia Tech’s School of ECE has utilized the two most prevalent pedagogical models of writing instruction currently available:

- the genre-driven, stand-alone technical writing course offered through the English department, and
- the integrated, discipline-specific approach based on Writing-Across-the-Curriculum (WAC) and Writing-in-the-Disciplines (WID) philosophies.

Our students are required to take a two-credit technical writing course intended to give them the requisite skills needed for the types of discourse they will practice in their major courses. Additionally, we have integrated writing into the ECE curriculum itself, which has become the predominant means of implementing technical communication. Five required courses (beginning at the sophomore level and continuing through the senior design experience) have been designated as communication-intensive: ECE 2031 (Digital Design Laboratory), ECE 3041 (Instrumentation and Circuits Laboratory), ECE 3042 (Microelectronics Laboratory), ECE 4000 (Project Engineering and Professional Practice), and ECE 4006 (Major Design Project).

The five-course sequence allows communication skills to be taught throughout the curriculum, giving students multiple opportunities to engage in writing and speaking situations applicable to both academic and professional settings. Collaboration between writing faculty and engineering faculty has resulted in the creation of several innovative, discipline- and course-specific writing assignments and in the improvement of assessment instruments and evaluation rubrics. Much attention has been placed on creating a learning environment that fosters the development of critical thinking through the use of both traditional academic assignments (such as lab reports and summaries) and nontraditional

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workplace-oriented assignments (such as user’s manuals and application notes). Thus, applied communications and transferability of skills are important goals of the UPCP.

**The Writing-to-Learn Theory**

Because the Undergraduate Professional Communications Program is strongly influenced by the principles espoused by both the WAC and WID movements, the basic tenets – “writing-to-learn” and “learning-to-write” – have become important assessment issues. We have been interested particularly in understanding how writing affects the acquisition and retention of knowledge. All of the writing assignments required in the communication-intensive ECE courses are derived from content covered within the course so that writing becomes a mode of learning – a way of reinforcing engineering content. As a result, we wanted to test the writing-to-learn theory by conducting research in at least one of the writing-intensive courses.

For over fifty years, developmental psychologists, social scientists, and linguists have been theorizing on the role language plays in the learning process. In the 1950s and 1960s, Jerome Bruner and his colleagues began studying cognitive processes, “the means whereby organisms achieve, retain, and transform information” [1, 2]. Their research pointed out that thinking seemed to develop most fully with the support of verbal language, particularly of written language. Lev Vygotsky’s seminal work, *Thought and Language* (1962), extended this premise, arguing that language is part of the “apparatus of thinking” [3], and A.R. Luria’s research (1971) asserted that “written speech… represents a new and powerful instrument of thought” [4].

One of the most important contributions to the “writing-to-learn” topic comes from Janet Emig, who contends in “Writing as a Mode of Learning” that “writing serves learning uniquely because writing as a process-and-product possesses a cluster of attributes that correspond uniquely to certain powerful learning strategies” [5]. Emig demonstrates how writing corresponds to learning by outlining the ways in which the writing process involves what Bruner previously argued are the three major ways of representing and dealing with actuality: we learn by “doing” (enactive); we learn by “deception in an image” (iconic); and we learn by “restatement in words” (symbolic) [5]. She conjectures that if reinforcement through this cycle of perception, thought and verbal action is a significant factor in retention, then writing is a “uniquely powerful multi-representational mode for learning” [5]. Taken as a whole, the arguments posed by Bruner, Vygotsky, Luria, and Emig lay the foundation for the importance of writing-across-the-curriculum and writing-in-the-disciplines.

While the writing-to-learn theory posits that writing can make a profound contribution to cognitive development, very little quantitative research has been conducted to test this claim. According to Russell [6], since quantitative experimental studies conducted in the early 1990s yielded “confusing results,” qualitative studies (estimated to be over 200) of college-level writing in the disciplines have predominated in recent years. Our focus at Georgia Tech has been on quantitatively assessing whether or not writing can sponsor learning.

**Research Methodology**

An undergraduate course in digital design presents a unique opportunity to examine the relationship between student performance in an engineering course and the requirement to complete technical writing assignments on the same subject matter. For this paper, three semesters of student performance on a relevant test problem in the Digital Design Laboratory Course will be analyzed. Over the three semesters there were no changes to the course instructors, course objectives, learning outcomes, or the structure of the final exam. The only significant change about the course was the type of technical writing assignments that were required each semester.

**Course Description**

As one of the five courses that are designated as “writing-intensive,” the Digital Design Laboratory Course is a core requirement that students normally complete as sophomores. Teaching faculty for the course includes a lead instructor who is responsible for engineering-content lectures and a technical writing instructor who delivers all of the technical communication-related lectures. Both instructors collaborate to create course-specific and discipline-appropriate writing assignments. The same two instructors have staffed the course for the three semesters that are included in this analysis. The course objectives and student learning outcomes have also remained unchanged. Because the course is required, no student self-selection issues are a factor in this analysis.

The structure of the course material can be divided in five content areas:

- Laboratory tools (hardware and software),
- Combinational logic design,
- Sequential logic design (state machines),
- Computer architecture and low-level programming, and
- Design applications.

Lecture and laboratory time devoted to each content area is consistent each semester, and an explicit weekly schedule is followed. Students complete laboratory exercises nominally once each week prior to a final project, with a comparable schedule for the shortened summer term. Some laboratory exercises involve a true writing assignment (a formal report or a summary report), while others require only simple compilation of results. For this course, students are typically required to complete three individual and three group writing assignments each semester. From one term to the next, the instructors vary which of the weekly labs are chosen as the basis for the writing assignments. One reason for the variation is to discourage plagiarism and recycling of work produced by students in previous semesters. Even though the writing assignments that are tied to the content area vary, the amount of lecture time allotted to each area remains the same. There is additional instruction provided by the technical writing
instructor that is related to the specific writing assignment
requirements.

The requirements of a writing assignment vary based on
the purpose of the document being produced, but in general,
writing assignments require students to explain concepts in
their own words, describe a design process, or articulate a
solution to a problem. In contrast, lab exercises without a
writing assignment simply require students to submit results in
the form of collected code listings, graphs, screen captures,
schematic diagrams, or other relevant figures. Consequently,
students must rely more upon critical thinking skills to
complete the writing assignments, especially with regard to
the more lengthy formal reports.

A practical final exam is given in the laboratory
environment near the end of each semester. Since specific
exam problems are based directly on earlier lab exercises that
may or may not be linked to writing assignments, it is possible
to compare student performance on exam problems whose
content is associated with specific types of writing
assignments.

Research Questions

This research tests the hypothesis that student
performance on final exam questions on course material that
was reinforced by the requirement of a formal report is better
than the corresponding student performance on the same topic
in another semester where there was no associated formal
report requirement.

One specific lab exercise stood out as a strong candidate
for this first look at the association between student exam
performance and writing assignments – the “Train Lab.” The
Train Lab is ideal to test this hypothesis for several reasons:

- it is an open-ended exercise, with some abstract thought
  required in the conception of a controller,
- it has subtle details required for the implementation of a
  working controller,
- the assignment is given early enough in the course so that
  retention can be tested at least several weeks later,
- it was explicitly tested in the practical final exam three
times since the summer term of 2002, and
- data exists for both terms with a formal report (Summer
  2002 and Spring 2003) and without a formal report (Fall
  2003).

The Train Lab is performed about midway during the
term. Students are given the definition of a simulated electric
train layout, with two trains, crossings, and shared track
segments, as shown in Figure 1. The two trains, if improperly
controlled, can collide at the crossings or anywhere along a
track segment where one train overtakes the other. Students
are also provided with a specific pattern of train movements to
be executed without collision, which varies from one term to
the next (not shown in Figure 1). They must develop an
automated controller for the two trains (a state machine, or
“finite state automaton”) and then implement it within a
programmable logic device.

A corresponding practical final exam problem requires
the student to design and implement a controller for a much
simpler problem, since it is one of about eight problems given
in an exam lasting only about 2½ hours. The simpler exam
problems typically require a controller with only 2-3 distinct
states, as opposed to the earlier lab exercises, which typically
require 8-12 states. But all of the details of sensing trains,
switching tracks, and controlling track power remain the same
in the simpler problem. These details, along with the
conceptual process of constructing a viable state machine
diagram, are the elements that must be retained from the
original laboratory experience.

Because of the limited time allotted for the exam, many
students do not finish all problems. Since there is no
sequential dependency of the problems, they are allowed to
attempt them in any order and skip any that appear to be too

\[\text{FIGURE 1} \quad \text{THE TRAIN LAB REQUIRES STUDENTS TO CONSTRUCT A CONTROLLER FOR TWO TRAINS THAT MUST TRAVERSE SPECIFIED ROUTES REPEATEDLY.}\]
difficult. Problems are graded by a teaching assistant or faculty member as they are completed. All problems must be solved correctly when first submitted for a grading “checkoff” in order to get a perfect score on the exam. Reduced points are given for a successful second attempt, but students are forced to move on to another problem if not successful on the second attempt. No rigorous attempt was made to standardize the different exams, but during each of the three semesters considered, multiple students achieved perfect scores.

In order to test the hypothesis, student performance on the specific Train-Lab-related final exam problem is analyzed over three semesters that required different writing assignments for the Train Lab. This research concentrates on two basic questions:

- Are students who had a formal report assignment on the Train Lab more likely to attempt the associated final examination problem than students who had no such assignment?
- Are students who had a formal report assignment on the Train Lab more likely to succeed on the associated final examination problem than students who had no such assignment?

The first research question addresses student confidence— their perception of their own competence. The second research question measures competence directly.

RESULTS

Even though the Digital Design Laboratory course is required of all electrical and computer engineering students, an analysis of student descriptive characteristics was conducted for the three classes to ensure that the student groups were comparable. This is important in order to eliminate other possible explanations for differences on final examination performance. In Table I, a comparison of student gender and ethnicity for each semester is presented.

The summary of the selected demographic variables shows very small differences among the students for each semester. There was some concern that the summer term students may differ in some systematic fashion from both fall and spring, because of the optional nature of summer attendance. Of particular concern was the issue that international students are represented disproportionately in the summer term. But using ethnicity as an indicator, this is not warranted. There is no discernable pattern of differences based on ethnicity or gender.

Another comparison method is to examine final grades in the course. This data is presented in Table II. While overall grade distributions appear similar across the three semesters, the percentage of “A” grades earned in the summer term is much lower than that of spring or fall, but the percentage of “B” grades is much higher. These departures in grade distributions are not found between this particular choice of spring and fall semesters.

Finally, participation in the cooperative education program was considered for the three semesters. This data is presented in Table III. Since co-op students are more likely to enroll in the summer, it is not surprising that a higher percentage of co-op students is observed for the summer semester considered in this study.

Summarizing the population characteristics of the three semesters, it is apparent that there are some minor differences in grade distribution and co-op status with regard to the summer semester. There would be greater cause for concern if the summer term were the only data set used to represent a particular case, but it is actually one of two terms in which a formal report was associated with the Train Lab exercise. Consequently, the three data sets appear to be satisfactory for comparison.
shows differences among the groups. In fall 2003, 64.0% of the students who attempted the problem successfully solved it, while the comparable figures for spring 2003 and summer 2002 are 75.2% and 77.6% consecutively. This data suggests that a larger proportion successfully solved the problem when they had previously worked on a formal report on the same topic.

<table>
<thead>
<tr>
<th></th>
<th>Summer 2002 (83 students)</th>
<th>Spring 2003 (173 students)</th>
<th>Fall 2003 (146 students)</th>
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</thead>
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<tr>
<td>Formal Report?</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>% Attempting Problem</td>
<td>91.6</td>
<td>63.0</td>
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<tr>
<td># Attempting Problem</td>
<td>76</td>
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<tr>
<td>% Success</td>
<td>77.6</td>
<td>75.2</td>
<td>64.0</td>
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<tr>
<td># Success</td>
<td>59</td>
<td>82</td>
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</tbody>
</table>

**DISCUSSION AND CONCLUSIONS**

The findings from this study show several promising trends that can contribute to our understanding of engineering education in general and discipline-specific writing instruction specifically. What is most apparent is that students who were required to complete a particular type of writing assignment were more likely to attempt to answer related exam questions and performed better on those questions.

Based on the data presented in Table IV, a higher percentage of students attempted the Train Lab final exam problem if they had been required to do a formal report assignment on the same topic. Students from both semesters with the formal report requirement were more likely to attempt the Train Lab problem.

The nature of the formal report assignment may help to explain why students who were assigned the formal report were much more likely to attempt to answer the Train Lab exam problem. Formal report assignments, compared to mere assembly of graphs and data, require students to record, synthesize, and articulate conclusions about the laboratory experiment. The skills that are needed for students to complete the formal report appear to impact their comfort with the corresponding material. This may explain why the percentage of students who attempt the Train Lab question is considerably higher for students who had completed a formal report.

The utility of the formal report as it relates to discipline-specific retention can be viewed in terms of building student confidence with subject material and enhancing performance on tests. The data on problem attempts may reflect greater student confidence or comfort with the material that was the focus of a formal report assignment. Success on the Train Lab problem, however, is more directly related to the performance-enhancement dimension. The variation in the attempt data for summer, as compared to the attempt data for spring, appears to support the argument that the formal report requirements, combined with the impact of more recently working on the material influenced student behavior on the exam. Students most likely felt more confident to solve the problem and were more willing to use exam time to attempt the question.

Turning to the second dimension of enhancing student test performance, the success data for summer is consistent with that of spring semester (the other formal report semester). Again, the differences of student success among the three semesters are obvious: only half the students in the fall semester class attempted the Train Lab problem, and of those, only 64.0% successfully solved the problem. These students were not as likely to attempt the problem, and those who did had a lower success rate than students from summer and spring semesters.

This research is encouraging for those departments that have adopted the discipline-specific writing instruction method. By integrating writing assignments with course material as done in the Digital Design Laboratory course, overall performance on an exam problem that was tied to the writing exercise was higher for students who completed a comprehensive writing assignment. How this finding can be used to enhance instructional methods is compelling.

First, content-based writing assignments may be an effective method for teaching course material that is critical to understanding subsequent material. Assuming that all course material is relevant, some topics necessitate a complete understanding in order for students to move successfully to the next level of material. The investment in a writing assignment that requires students to present, synthesize, and analyze information may be worthwhile.

Second, assignments such as formal reports can be a tool for instructors to use for particularly complex material. Writing assignments, such as the formal report, offer one method for students to sort out complex material. In the long run, the additional time and resources needed to require such an assignment could be worthwhile, given the challenge many engineering instructors face.

Exam problems were constructed to be of similar difficulty based on the instructor’s experience and perception; there was no rigorous standardization of the exam across semesters. But it is worth noting that this study was not conceived until after the last of these three exams (fall 2003) had been given. Although the instructors were familiar with the writing-to-learn concept prior to that, it had never occurred to them to test it in this way until all of the data had been acquired.

The implications for further research are enormous. Data from the Digital Design Laboratory course will be collected over the next several semesters. One key variable that will be introduced is varying the type of writing assignments that will be used to teach the train lab problem. Another writing-intensive engineering course will be added to this analysis to ascertain the impact of writing assignments on written test only.

Session T1F
REFERENCES


