AC 2007-1875: WRITING PROGRAM IMPROVEMENTS FOR A MATERIALS ENGINEERING LABORATORY COURSE

Anastasia Micheals, San Jose State University

Anastasia Micheals, materials researcher and instructor in materials engineering, works with a wide variety of materials, including metals, ceramics, composites, and polymers. She has more than 13 years experience in industry, government and consulting in the areas of materials characterization, analysis, and processing.

She holds an M.S. in Materials Science and Engineering from Stanford University, and currently teaches Materials Engineering at San Jose State University. Courses include introductory materials engineering, electrical properties of materials, and materials characterization. She also does course development work, for the electrical properties of materials laboratory class, and for a new electron microscopy course. In addition to teaching, Ms. Micheals manages the SEM Laboratory for the SJSU Materials Characterization and Metrology Center [MC]2, where she performs and directs research and materials characterization.

In her consulting work, Ms. Micheals applies her experience to analyze failures, including materials failures due to processing and manufacturing defects, and detection and identification of trace elements in solids, liquids and gases.

She is a member of the American Society of Metals (ASM), an officer of the San Francisco Bay Area Chapter of the Electronic Device Failure Analysis Society (EDFAS), and is Treasurer for the Engineering Sciences section of the American Academy of Forensic Sciences (AAFS), as well as Program Chair for the AAFS 2007 Annual Meeting.

Emily Allen, San Jose State University

Dr. Emily L. Allen is Professor and Chair of the Chemical and Materials Engineering Department at San José State University. She conducts research in materials synthesis and fabrication for applications in nanoelectronics. Her teaching portfolio includes courses on electronic and magnetic properties of materials, materials transformations, microelectronics processing and senior design.. She is Director of SJSU's Materials Characterization and Metrology Center and has been awarded funding from NSF, DARPA and DMEA in support of this Center and its research on nanoscale materials.

Jeanne Linsdell, San Jose State University

Dr. Jeanne Linsdell is Director of Technical Communication, SJSU College of Engineering. Over 25 years at SJSU, she has developed and taught technical writing and earth and environment classes as well as the graduate research and writing class. Outside the classroom she works with new and mature organizations that need to adapt for greater productivity, focusing on training in communication, human relations, organization behavior, teamwork, conflict resolution, ethics and effective problem solving.

Writing Program Improvements for a Materials Engineering Laboratory Course

Abstract

The Chemical and Materials Engineering Department at San José State University offers introductory courses in materials engineering (MatE 25) and electrical properties of materials (MatE 153) to about 500 engineering students every year. Almost all engineering majors are required to take at least one of these classes, both of which have laboratory components requiring a significant amount of writing. The writing assignments in MatE25 and MatE153 have traditionally been in the format of short journal articles, which is not necessarily the most appropriate, or most useful, format to teach engineering students. The reports are graded by individual lab section instructors, which brings an element of unfair inconsistency to the student overall course grade. Writing quality is often weak, and in addition many students do not read or heed the grader's remarks. The scores on individual student lab reports do not increase over the course of a semester as a rule, which may be an indication that no real improvement is happening during the delivery of the course. This may in part be due to lack of explicit instruction in what constitutes an appropriate report and how it is to be structured.

To address these issues, a two-semester research program was developed with the objective of ensuring that the time needed to write and grade these writing assignments was well spent. The primary goals of the program were to develop a new formulation for the writing assignments that was more reflective of and appropriate for real-life engineering situations, to clarify the iterative communication loop between student and teacher regarding the effectiveness of the writing, and to create an evaluation process that would promote consistency among multiple instructors.

The writing assignments were reformulated in the form of contextual assignments, modeled on real-world settings in industry, and covering a range of complexities, from a short engineering report, to a long engineering report with an executive summary and cover letter. Student guidelines were created to identify various types of engineering reports, subjects typically addressed in these reports, and appropriate content for each section. A rubric for evaluating the reports was developed and used in several sections of MatE 153. Our conclusions are that the rubric makes grading faster and allows the instructor to easily and consistently provide accurate and detailed feedback to students. We have also observed that the majority of students respond to the rubric feedback, and improved their performance in specific areas on subsequent assignments. A cross-grading exercise was performed in which each instructor graded up to 6 student papers. The exercise showed that the grade derived from the rubric closely agreed with the holistic grade determined by the instructor without using the rubric. It also showed that different instructors, grading the same paper, arrived at numerical scores that were within 7% of each other.

The assignments, rubric, and student guidelines have now been incorporated into all sections of the MatE 153 lab. The rubric and the assignments are easy to modify and it is likely that these materials will be extended to other courses in the Department and College.

Keywords: Writing, laboratory, engineering reports, contextual assignments, rubric

1. Introduction

Engineers are expected to communicate with a variety of written formats[1], including memos, letters, short narrative engineering reports, longer detailed engineering reports and journal articles. Traditionally, engineering writing has been taught separately from discipline-specific classes, however writing across the curriculum is becoming the standard. Many engineering colleges are developing programs which use "writing-in-the discipline" to teach engineering composition[2,3].

A primary challenge is determining the most effective way to integrate the writing component with the subject. One promising method is contextual writing. The literature[4-6] indicates that students perform better on assignments that have a connection to the real world. Compared to the abstract term paper of earlier generations, contextual assignments can be more engaging, requiring more imagination to complete, and provide a direct connection from the learner to the world of the expert. They give the student a look at what the future holds.

Engineering faculty are engineers, not writing teachers, and are primarily concerned with teaching and measuring student understanding of engineering subject matter. However, when writing is integrated into a curriculum, almost as much grading time may be spent correcting writing style, grammar, punctuation, formatting errors, and even spelling, as is spent in evaluating conceptual mastery. To the learner who has not mastered the elements of style and format, corrections and notes written in a graded paper's margins may seem cryptic or arbitrary. The comments provided by an engineer also tend to be directive, and thus less helpful in teaching than facilitative or suggestive comments are[7]. In any case it is suspected that many students do not read or heed the grader's remarks.

One way to simplify the grading process for both the teacher and the student is by using rubrics. A rubric is a subjective scoring guide, which makes explicit the performance criteria in relation to a scale or grade. The wording of the rubric is carefully chosen to describe the expected level of performance. The utility of the rubric is that it contains the essence of the grading criteria and can make grading more fair, consistent and efficient.

2. Background

At San Jose State University, engineering students must pass several courses in English composition (English 1A/1B) as well as an upper division technical writing course (E100W). The General Education curriculum contains a significant writing component, and engineering students are given specific instruction in engineering writing in several required classes, such as Introduction to Engineering and Engineering Reports (E10 and E100W). In these classes they use a variety of formats, including memos, letters, engineering reports and journal papers. They use these written formats in other, discipline-specific, courses. The Chemical and Materials Engineering (CME) department administers two such classes, the introductory courses in materials engineering (MatE 25) and electrical properties of materials (MatE 153). All engineering students (except computer and software engineering majors) are required to take one of these two classes. These courses have laboratory components that require a significant amount of writing (three to four written reports each).

The MatE25/MatE153 programs typically comprise a total of 4 lecture sections and 10 to 15 lab sections per semester, depending on enrollment. Typically 10 or more individual instructors are involved per semester. The instructors are regular or adjunct faculty, part-time faculty and a few graduate teaching associates. The laboratory is a once a week, 3-hour class. The class is structured around a short (20 to 30 minute) lecture on the experimental topic, with the rest of the period devoted to the experiment.

The writing assignments in MatE25 and MatE153 traditionally used the format of short journal articles. This format is appropriate to the course content, as both of these classes are more engineering science than engineering design. However, scientific journal article format is not necessarily the appropriate format to teach engineering students. In addition, and for many reasons, writing quality on these written reports is often poor. These reasons include varying levels of students' experience with both speaking and writing English, lack of mastery of this form of written communication, and confusion surrounding differences in engineering writing standards and English composition standards. Engineering 100W is not a pre-requisite for either of these courses as they are typically taken in the sophomore or first semester junior year. Thus there is wide diversity in student skills and experience with engineering writing.

It is our experience that the scores on student lab reports do not increase over the course of a semester as a rule, which may be an indication that no real improvement is happening during the delivery of the course. This may in part be due to lack of explicit instruction in what constitutes an appropriate report and how it is to be structured.

Given the amount of time spent in MatE 153L/25L on writing and grading lab reports, as well as the exposure of so many engineering students to these courses, we considered ways to ensure that report writing and grading is time well spent for both students and faculty. A program was developed for the MatE 153 laboratory to improve the writing and grading of laboratory reports. This program, described below, is currently impacting about 250 students per year. The results of this program have been shared with faculty of the College and the program will be extended to the MatE 25 laboratory. The work was funded by a Research and Teaching Development Grant from the Dean's Office of the College of Engineering.

This program had two goals:

- To redesign the current writing assignments to be more appropriate in relation to both future academic writing, and the engineering workplace.
- To create a rubric which clarifies, to both the students and instructors, the expected level of performance.

In Section 3, we describe the new student assignments and writing guidelines included in the laboratory manual. In Section 4 we present the grading rubric and describe its use. Section 5 discusses instructor and student response to the new writing instruction.

3. Reformulated Assignments

A student guideline was created for inclusion in the laboratory manual, which describes the process for writing an engineering report and discusses the various aspects of the engineering reports. The process is presented to the student as being similar to writing a laboratory report. The main differences are explicitly highlighted. Specifically:

- The audience: instead of writing to the instructor, they are writing to a colleague, manager, or client.

- The purpose for writing: instead of demonstrating their understanding of the laboratory experiment, they are writing to describe the work done, the results, and their relevance to a particular question or problem.

- What content is appropriate? For a laboratory report, the subject, laboratory instructions and the instructor give cues about what information is important to include. We emphasize that, for an engineering report, the writer/student is being considered as the expert, and is responsible for deciding, based on their experience, education and training, the audience and purpose for writing, what information is relevant, and how much detail should be included.

Almost all engineering students are exposed to the general engineering report format: Introduction, Experimental Procedure, Results, Discussion and Conclusions. In these assignments, the same general format was utilized with minor variations in each contextual assignment.

Four new assignments were created. Each assignment had a different contextual situation, designed to relate the abstract laboratory experience to a hypothetical real-life situation. Each assignment was designed to be more challenging than the next, both in the subject matter and the complexity of the report format. Each assignment presents a short narrative, describing an engineering job and assignment, and presents some guidelines as to what content is appropriate. In the rest of the assignment, the audience is identified, and guidelines for length are given. The student's task is to extract relevant information from the experiment and effectively communicate that information in writing.

A short description of the laboratory experiment subject, the specific narratives and tasks for the writing assignment are described below. For an example of a complete narrative, see Figure 1.

- Assignment 1. Metal Resistivity - Short Engineering Report
  - Your company fabricates copper wire. Elemental analysis of a metal wire sample showed a slightly elevated level of impurities. Use resistivity change with temperature to determine if these impurities adversely affect the reference resistivity and the temperature coefficient of resistivity.

- Assignment 2. The Hall Effect in Semiconductors - Short Engineering Report with Cover Memo

- Your company, SemiTech, wants to buy doped silicon wafers from a bulk supplier, at a 20% discount over the current supplier. You use the Hall effect to test a sample to see if it meets your requirements: the dopant concentration must be between 8×10^{17} and 2×10^{18} carriers per cm^3.

- Assignment 3. Semiconductor Bandgap Measurement - Long Engineering Report with Cover Letter

  - SemiTech has a subsidiary company called SemiGap Engineering, which processes raw gallium arsenide and gallium phosphide to produce wafers. Since using the new wafers, your devices have not been working properly. You suspect that someone in SemiGap has been shipping the wrong wafers or mixing up the labels, so you test a sample wafer to determine its bandgap. If the semiconductors are labeled correctly, the experimentally determined bandgap should be around 1.42 eV for GaAs or 2.2 eV for GaP.

- Assignment 4. Temperature Dependence of Semiconductor Resistivity - Long Engineering Report with Executive Summary
  - SemiTech manufactures semiconductor devices, including germanium transistors, which will be used by NASA's Jet Propulsion Laboratory in a new Mars orbiter. The orbiter will see a range of temperatures, thus JPL engineers need to know the dopant concentration and electrical behavior of the germanium as a function of temperature.

Writing Assignment - Long Engineering Report with Executive Summary
Lab 9. Temperature Dependence of Semiconductor Conductivity

1. Background
Thermal control is an important issue in astronautics. Spacecraft thermal control seeks to ensure that constant temperature is maintained inside the vehicle, to ensure correct operation of electronic equipment, and to avoid damage. Any built-up heat must be transferred through the vehicle wall and dissipated to space.

2. The Job
Your company, SemiTech, manufactures semiconductor devices, including germanium transistors. They proposed supplying NASA's Jet Propulsion Laboratory (JPL) with doped germanium transistors to be used in a new Mars orbiter. JPL accepted your proposal. Now, the JPL engineers need more details regarding the electrical behavior of your doped germanium. JPL will design the electronics of the orbiter based on the specifications you provide, so it is important to be accurate. They need to know the following:

- The electrical behavior of the germanium as a function of temperature
- The dopant concentration in the germanium

3. The Assignment
The report will go to the Thermal Control Technical Lead at JPL, Dr. Morgan Melas. Write a long engineering report describing the behavior of semiconductor conductivity with changing temperature. In addition, since Dr. Melas may not have the time to read the entire report, write an Executive Summary.

In your Executive Summary, explain why and how doped germanium is sensitive to temperature. Recommend the temperature range over which the electronic properties should be stable. Let her know if there are upper or lower temperature limits that should not be exceeded.

Figure 1. A Sample Narrative from the Final Writing Assignment.

4. Rubric

A rubric was created and is provided to both the instructors and the students in their lab manual. The rubric was designed to do several things for the student. First, to describe what is expected of the student. Second, to unambiguously communicate to the student how well they have met the expectations. Third, to scaffold improvement in student writing .

In format, the rubric is laid out as a matrix of attributes upon which the student is being graded, against possible levels of performance. In this case, we chose three broad categories of focus, each contributing to a percentage of the final score. They were:

- Writing Mechanics - 28%
- Writing Quality - 8%
- Technical Quality - 64%

These categories and weights, while not arbitrary, were chosen based on the biases of the authors and the focus of the particular course. Others may choose different categories and weights.

Each of these categories is broken down into further itemized list of attributes, each with an appropriate weight. Each student's assignment is scored on how well it meets each of these attributes. For each attribute, the assignment is scored from unacceptable to excellent, or 1 to 4 respectively. Each attribute score is multiplied by the category weight, and then summed to obtain the overall grade. The maximum number of points in this case is 100. By way of example, the Writing Mechanics portion of the rubric is shown in Figure 2.

Each graded assignment is returned to the student, with a copy of the marked rubric, before the next report is due. Thus the rubric is available to the instructor and the student as a teaching and learning tool. The instructor uses the rubric to provide consistent and explicit feedback to the student, and student is able to review the rubric, quickly see the areas where they performed poorly, and work to improve their performance on the next assignment.

Scoring Attribute	Unacceptable 1	Marginal 2	Proficient 3	Excellent 4	
Writing Mechanics					Wt
Assignment Instructions and Requirements	Assignment instructions not followed	Some assignment instructions followed	Most assignment instructions followed	Report fully complies with instructions & requirements	1
Grammar, mechanics and spelling	Consistently inadequate grammar, mechanics and/or spelling; Errors impair meaning	Many errors, which affect writing clarity	A few errors, which do not impair meaning	Consistently correct use of grammar, mechanics and spelling	1
Figure and Table Format and Quality	Figures/tables consistently not labeled or not referenced in text	Some figures/tables missing labels, missing descriptive captions, not referenced and/or not discussed in text		All figures/tables neatly labeled with title, figure no. and descriptive caption, discussed, explained in text	2
Units and Significant Figures	No units given for any table headings, plot labels or values; or wrong number of significant figures	Some table headings, plot labels or values missing units and/or wrong number of significant figures		Tables formatted correctly, with all table heading; Plot labels and values given with correct units and significant figures	2
Formulas	All symbols and formulas written by hand	Some symbols and formulas handwritten or word-processed		All symbols and equations written with equation editor and mathematical notation; All variables defined, all equations numbered	1

Figure 2. Writing Mechanics Portion of the Rubric

5. Student and Instructor Responses

The primary question is whether the new assignments and rubric are improving student mastery of writing. At this time, the quantitative evidence is preliminary. Data is available from two sections in Spring 2006, and one section in Fall 2006. All three of these classes were taught by the author (Micheals). The data from Spring 2006 is incomplete. The rubric was revised after the first assignment was completed, so only the last three assignments can be compared. Figure 3 shows change in scores as a percentage of the score given on the first assignment in each section where the rubric was used. This data shows that the students consistently improved their performance from assignment to assignment. These results suggest that the majority of students are able to understand and respond to the rubric feedback. For further validation of the rubric, we plan to gather statistics from all sections of the class, and from different instructors, to eliminate the effect of instructor and students from the data

The instructors for the lab sections change frequently, and in addition the quality of instruction varies with the experience and education of the instructor. Frequently, the lab section grades given by different instructors in the same semester differ by a large percentage, for example from an average grade of 75 from instructor A to an average of 95 from instructor B. One of the goals of the rubric was to make grading more consistent between different instructors. We expect that if this goal is met, then the deviation between average grade from instructor A and instructor B should be small. In Fall 2005, before the new program, there were six sections taught by 5 instructors; the average grade was 84, with a standard deviation of 4.5. During Fall 2006, of the four instructors and four sections using the new program, the average grade was 87, with a standard deviation of 2.6.If the reduced deviation holds in the future, then the rubric will be validated.

The rubric allows for more uniformity in grading between instructors, and is consistent with holistic grading results. Several faculty members vetted the rubric during its development. Three MatE 153 laboratory instructors used the rubric during the Spring 2006 semester, and participated in a cross-grading exercise, where each instructor graded the same student papers. Each instructor graded up to 6 papers. The exercise showed that the grade derived from the rubric closely agreed with the holistic grade determined by the instructor without using the rubric. It also showed that different instructors, grading the same paper, arrived at numerical scores that were within 7% of each other.

The rubric makes grading faster compared to a holistic grading process, especially for instructors who are familiar with the assignments and the rubric. The time spent grading reports with the rubric compared to the holistic grading process was observed to decrease, on the order of 25%.

	Writing Mechanics Max Score=28		Writing Quality Max Score=16		Technical Quality Max Score=56	
	Average Score	Change from Initial (%)	Average Score	Change from Initial (%)	Average Score	Change from Initial (%)
Spring 2006 Section 1 N=17						
Assignment 2	24	-	13	-	41	-
Assignment 3	26	8	12	-8	41	0
Assignment 4	27	12	15	15	46	12
Spring 2006 Section 2 N=16						
Assignment 2	26	-	15	-	51	-
Assignment 3	28	8	15	0	53	4
Assignment 4	28	8	15	0	55	8
Fall 2006 Section 1 N=17						
Assignment 1	24	-	6	-	54	-
Assignment 3	22	-8	6	0	47	-13
Assignment 3	26	8	7	17	65	20
Assignment 4	26	8	8	33	60	11

Figure 3. Change in average scores over a semester. Initial score refers to first use of rubric in that section.

6. Conclusion

Over the last two semesters, this program has positively impacted the over 100 students who used the new assignments and rubric, by specifically engaging them with contextual assignments, identifying areas of strength and weakness, and allowing them to improve deficiencies. The assignments, rubric and student guidelines were incorporated into the laboratory notebook starting with the Spring 2007 semester, and are now used in all the MatE 153 laboratory sections. Additional data will be collected in Spring 2007 with all sections using the new program, which should provide final conclusions regarding grading effectiveness and improvement in student scores.

Discussions are underway within the Department and College with respect to other faculty incorporating similar rubrics and assignments into their classes. Based on experiences with the cross-grading workshop, a short training session will be held at the CME Lecturer Orientation (held in August and January every year), so that new part-time instructors can learn how to use the rubric.

7. Acknowledgements

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