

**THE FOUNDATION SERIES ON CORROSION: INTEGRATING SCIENCE, MATH,
ENGINEERING & TECHNOLOGY IN A LAB SETTING**

Linda Vanasupa, Heather Smith, Blair London, Katherine Chen, David Niebuhr, Lanny Griffin

California Polytechnic State University, San Luis Obispo, CA 93407

Jeff Jones

Cuesta College, San Luis Obispo, CA 93406

Abstract

We have developed a laboratory module focussing on the subject of corrosion. The module itself is designed to be completed in one three-hour session. It consists of three parts: I. The Impact of Corrosion Media, II. The Impact of Corroding Materials, III. The Impact of Anode/Cathode Sizes. Our objectives in developing this module were to address the need for clear bridges between math, science and technology in the engineering curriculum and to provide a means of faculty development primarily at community colleges. As a result, it was designed to allow the engineering student to experience the synergy of science, math and engineering technology in a laboratory setting. Recent findings in learning theory research were used in the design of the module to reach students of diverse learning styles. Our targeted audience is sophomore engineering majors at community colleges and institutions without Materials Science and Engineering programs. In this paper we will present the module, its goals, objectives and performance criteria, and the preliminary results of its implementation.

I. Introduction

Each year, private industry spends millions of dollars in an effort to educate their engineers to meet their company's increasingly demanding goals. They continue to request engineers who are not only educated in the fundamental sciences and applications of their field, but possess stronger communication and teamwork skills^{1,2}. The National Research Council's (NRC) Board on Engineering Education recognizes this need and has called all engineering colleges to provide more exposure to interdisciplinary/cross-disciplinary aspects of team work, hands-on experience, creative design, and exposure to "real" engineering and industrial practices, identifying integration of key fundamental concepts in science and engineering as the number one principle for new engineering curricula and culture³. Yet curricula generally require engineering students to ingest subjects from the resident specialists--separately and sequentially as if each subject was wholly independent of the other. As depicted below in Figure 1, this experience is much like eating a lemon-meringue pie, one ingredient at a time: while some ingredients like sugar (physics) will taste okay, other ingredients like flour (mathematics), lemon juice (chemistry) or raw eggs (thermodynamics) will be rather unpalatable. The engineering student doesn't experience the synergy of taste that results when these ingredients are properly combined (Figure

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2). He or she just remembers their distinct and unpleasant flavor, hoping never to eat them again! This is a great tragedy, especially since understanding and being able to use these tools is critical to engineering problem solving.



Figure 1. Today's Engineering Curricula. To the engineering students, taking courses that have seemingly no relationship to one another can be like eating a lemon-meringue pie, one ingredient at a time. The subjects are a bit hard to swallow!

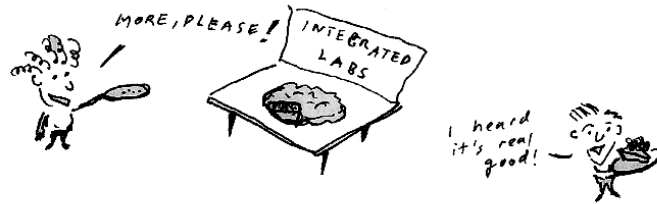


Figure 2. The Envisioned Engineering Curricula. In an ideal world, engineering students would have the opportunity to taste the multiplicity of subjects as a synergistic whole.

This lack of clear bridges between subjects like math and science in engineering curricula is no doubt a contributing factor in the high attrition rates reported by engineering programs⁴. Even worse, it produces engineering graduates who may understand the principles of science and mathematics in their separate contexts, but are unable to use them to solve technological challenges. Thus, there is a need to provide a systematic integrated experience for engineering students.

In 1990, The National Research Council in their report to Congress, identified MSE as a key area to maintaining the nation's competitive edge in technology⁵. Yet half a decade later, in a panel discussion of the Materials Division of the American Society for Engineering Education national conference⁶, MSE educators representing a broad range of perspectives conceded that there has been little change in the MSE education since the NRC's report. This is in part due to the "glacial" pace of change at universities.

Like the NRC, we feel that a strong MSE foundation for engineers is essential, as all engineering designs hinge on the performance of their materials. The introductory MSE course is typically the only MSE course that non-MSE engineering majors take during their undergraduate tenure. Referring back to the analogy of engineering education and a lemon-meringue pie, the

introductory MSE course is often experienced like a seemingly peripheral and unpleasant dose of baking soda.

To address some of these issues, we set out to develop a series of laboratory modules that integrate science, and math into engineering and technology applications. We call this set of modules the “Foundation Series in Materials Science and Engineering.” Our intention in developing the modules was to make use of the findings from learning theory to enable us to reach students of diverse learning styles.

This paper describes the beta version of the module which was developed as part of a “Proof of Concept” grant from the National Science Foundation (NSF Grant#DUE-9952609).

II. The Foundation Series Paradigm

The module that was developed focuses on the topic of corrosion. We modeled the design of the module after our goals and objectives that were embodied in our paradigm for the Foundation Series (FS) modules. This paradigm is depicted in the diagram in Figure 3. The main features are that it: 1) is interdisciplinary, systematically integrating science, math (statistics in particular), and engineering technology; 2) utilizes exercises that are designed to reach students of multiple learning styles; 3) is designed to develop teamwork and communication skills.

Our paradigm loosely follows McCarthy’s adaptation⁷ of Kolb’s learning cycle⁸. As shown, it begins with a reason for undertaking a study and is followed by facts (“Discovery of the Problem: What? Why?”). This stage is followed by a discovery activity or experiment (“Definition of Test Parameters”, “Plan Experiment”, “Set-up and Run Experiment”). The final sections contain a series of questions that challenge the learner to apply the concepts to an unknown situation (“Analyze Results”). It incorporates components from all learning styles. Incidentally, the Kolb indicator is only one of the many learning style indicators. Research shows that to engage all learners, it is simply important to utilize the complete range of learning styles of any indicator⁹. The FS paradigm incorporates exercises to develop communication skills (“Communicate Results”), a sense of engineering technology (“Reality Check”), and the basic ability to work in a team setting.

III. The Foundation Series Module on Corrosion

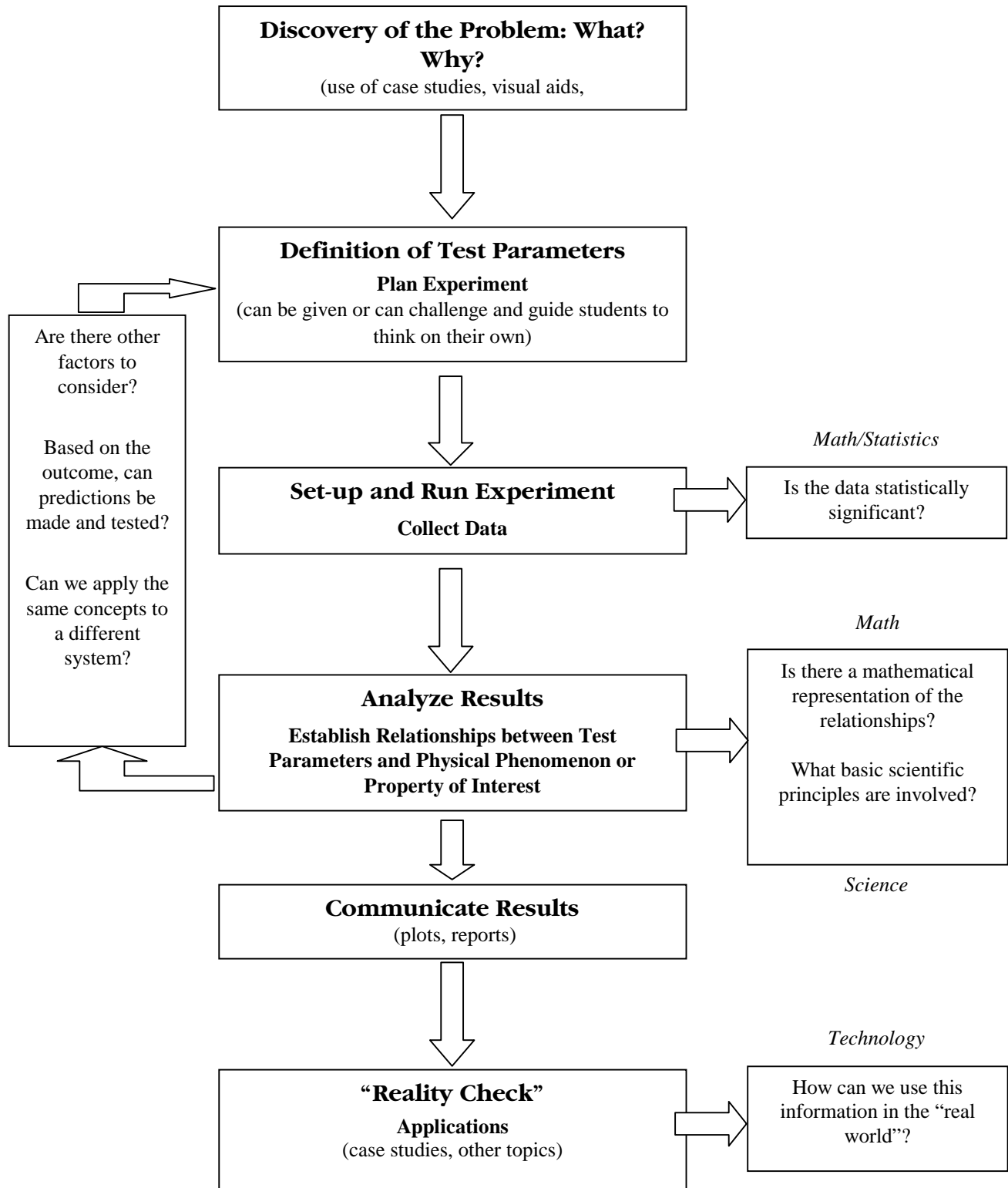
For the proof-of-concept work that we conducted, we fully developed the FS module on corrosion. This module consisted of three parts, each addressing a different aspect of corrosion. Specifically, Part I addresses the impact of corrosion media, Part II addresses the relative corrosion potential of different metals and Part III deals with the impact of the relative sizes of the cathode and anode. This module has a specific set of learning objectives as shown in Table 1. The learning objectives for a traditional lab on corrosion are listed in the left-hand column. Using the paradigm, our hope was to add the learning objectives as listed in the right-hand column. As you can see, many of the objectives focus on using statistical tools in gathering and interpreting the data.

Learning Objectives: FS Module on Corrosion	
<i>A. Specific Knowledge to be gained (objectives typical of traditional MSE labs on corrosion):</i>	<i>B. Abilities to be developed through the FS paradigm (“value-added” to current labs):</i>
<ol style="list-style-type: none"> 1. Calculate corrosion current from voltage measurements, a known resistance and Ohm’s law. 2. Calculate corrosion rates from sample dimensions and corrosion currents. 	<ol style="list-style-type: none"> 3. Explain the natural variation in physical measurements. 4. Describe how variation can be reduced through averaging. 5. Describe how replication can reduce variation. 6. Determine standard deviation from a data set. 7. Explain the difference between variation within and variation between sets. 8. Exercise creative thinking through brainstorming.. 9. Predict the relative corrosion potential between two metals on a Galvanic Series. 10. Critique the physical significance of the corrosion current and potential in a simple engineering application, such as a powering a light bulb. 11. Conduct a simple comparison of means to test for true variation between sets. 12. Design a simple corrosion protection system based on the principles learned in the experiment. 13. Work in a team setting toward common goals. 14. Communicate numerical information in an appropriate graphical form.

Table 1. Learning Objectives for the FS Module on Corrosion.

The module is designed to be completed in 1 3-hour laboratory session. However, students must complete about 1-hour’s worth of preparatory work in order for the lab to be completed in 3 hours. The background reading along with the module information can be found by visiting www.mate.calpoly.edu and following the links to the Foundation Series. At this point, the reading includes information on corrosion and information on statistics. The statistics reading is included for those students who have not had statistics. In the sections below, we describe the activities of each of the three sections of the Module.

PARADIGM FOR THE FOUNDATION SERIES MODULES



Prior to Coming to Lab

Before attending lab, the student is required to read the lab manual. The student manual also includes a CD-ROM containing animations. The CD is designed to reach students whose dominant learning style may be visual or auditory. It also includes short video clips of the lab set up and procedures. We estimate that the preparation time for the lab is approximately 1 hour. The preparation is critical to the success of completing the lab in the allotted 3 hours.

Part I-The Impact of Corrosion Media

To begin the lab module, students observe ordinary steel nails that have been submerged in regular tap water, boiled tap water and tap water with potassium chromate (a corrosion inhibitor). One sample also includes a galvanized nail with the steel nail. The module includes a poster that shows examples of different types of corrosion. During the approximately 10-15 minutes of this first part, students observe the relative extent of corrosion on the specimens and record this information in their lab sheet (see Appendix). They are also required to jot a brief explanation of the phenomena that they observed. For example, the specimen containing both a galvanized and non-galvanized nail has a white corrosion product on the galvanized nail, yet the steel nail is free of rust. They are to explain that the galvanized nail acts as a sacrificial anode and rusts instead of the steel nail.

Part II-The Impact of Corrosion Materials

This portion of the lab takes about 1 hour and 15 minutes. During the course of this hour, the students measure the corrosion potential of 5 metals: Aluminum (Al), Zinc (Zn), Copper (Cu), Tin (Sn), Titanium (Ti), and Stainless Steel (SS). Graphite is used as the cathode and the corrosion potential of each metal is measured twice in a randomized set of runs.

The students begin by generating the run order for the 12 measurements. Using a die, they generate the run order and record this in the laboratory worksheet (see Appendix). Next, they conduct the 12 measurements and plot them using a dotplot graph. The idea is using a dotplot is to give the students a graphical means to observe the numbers. This enables them to quickly visualize the relative size of the measurements and the range of the measured values.

The students then calculate the means for the measurements and complete the rest of the laboratory worksheet. The questions on the worksheet lead the students to consider the idea of variation in the measurements. They also must consider the size of the variation and whether or not they can draw sound conclusions based on the variation that exists.

Part III-The Impact of Relative Surface Area of Cathode and Anode

After completing Part II, the students have a sense of the relative corrosion potential of the materials that were measured. They use this information to determine which electrode is the cathode and which is the anode when Cu and Zn are used. During the course of this Part, which lasts for approximately 40 minutes, the students measure the corrosion rate in two different

cases. In one case, the electrodes will have the same surface area. In the other, the surface area of the cathode is ~50 times larger than that of the anode.

The corrosion rate is measured by first immersing both electrodes into the corrosion cell. Their initial corrosion potential is measured with a voltmeter. Then a 1 Ohm resistor serves as a shunt to connect the electrodes. The students monitor the voltage dropped across this resistor over the course of five minutes at 20 second intervals. This measurement is repeated with the smaller anode. The students then complete a series of calculations and questions on the laboratory worksheets (also included in the Appendix).

IV. Results & Discussion

At the time of this writing, 125 engineering students have our module. The students completed the module along with seven other experiments over the course eight weeks. Before completing any of the laboratory experiments, all students took a pre-lab survey to determine their learning styles and attitudes. One of the things that we discovered implementing the module was that many of the students did not complete the surveys. As a result, we do not have complete information on all 125 students. Only 27 respondents completed both surveys. However, we were able to evaluate the performance of 75 students against the performance criteria.

Learning Styles, Attitudes & Demographics

The demographics of the 27 respondents that completed both pre and post surveys are summarized in Table 2 below.

N=27

Learning Preference		Gender	Year	GPA	Ethnicity
Pre-Test	Post Test				
Concrete = 14	Concrete = 18	Males = 15	Freshmen = 1	4.0-3.5 = 3	Amer. Indian = 0
Abstract = 13	Abstract = 9	Females = 7	Sophomores = 4	3.4-2.5 = 16	African Amer. = 0
		N/A = 5	Juniors = 10	2.4-1.5 = 3	Asian = 5
			Seniors = 7	1.4-1.0 = 0	Hispanic = 2
			N/A = 5	> 1.0 = 0	Pac. Island = 0
				N/A = 5	White = 14
					Other/None = 6

Table 2. Demographics of the 27 respondents.

There were 27 questions on the pre-survey (see the Appendix for the complete text of the questions and the results) that were designed to allow us to evaluate the learning styles of the respondents. Kolb's model includes two main styles that are categorized as concrete learners and abstract learners⁸. *Concrete experience* (CE) or *sensing/feeling* in the Kolb typology are those who are immersed in the experience, giving preference to feeling over thinking or logic. They tend to be adaptable, intuitive and involve themselves in the activity. Those who are categorized in *Abstract conceptualization* (AC) or *thinking* tend to approach things logically and systematically. Thinking is emphasized over feeling and the learning is "concerned with

building general theories rather than intuitively understanding specific situations.”¹⁰ According to the preliminary results, there was a 50%/50% split in the CE and AC types before the lab experiment. Testing afterwards resulted in 67% CE and 33% AC types. Due to the small sample size, however, we cannot conclude that this shift in the distribution of CE and AC types is statistically significant. The complete statistics for phase II of the project will be available at www.mate.calpoly.edu (follow the links to the Foundation Series).

There was a 2:1 ratio of males to females in the test group. Although the course is designed for sophomores, roughly 75% of the students were juniors or seniors. Roughly 75% of the students had a grade point average of “B.”

Performance Criteria
1) Sketches a schematic representation of the exchange of electrons that takes place during the corrosion process, including an identification of anode, cathode, oxidation reaction, reduction reaction and the corroding substance.
2) Explains how the chemical and material components within a corrosion medium are involved in the corrosion process.
3) States the need for randomization in experimental replication and performs such a randomization.
4) Uses a calculator to compute basic descriptive statistics: sample mean and range.
5) Creates comparative dot plots of data.
6) Uses the comparative dot plots of the data to formulate a hypothesis about the relative corrosion potential of two different metals (i.e., is one more anodic than the other or is the data inconclusive?)
7) Explains the purpose of replication in an experiment.
8) Describes the qualitative impact of sample size, process variation, and difference that you are trying to detect on the precision of the estimates.
9) <i>Avoids erroneously inferring that a greater mean voltage necessarily implies that the one metal has a greater corrosive potential than another.</i>
10) <i>Recognizes the need for further analysis to draw statistically valid conclusions.</i>
11) Interprets the descriptive statistics: sample mean and range.
12) Recognizes and lists factors beyond corrosion factors that must be considered a given engineering application.
13) Uses a galvanic series to predict which of two metals is more likely to corrode if both are in contact with one another.
14) Creates a time series plot with Voltage and time
15) Predicts the impact of the relative size of the cathode/anode area on corrosion rate.
16) Cites examples of instances where corrosion has an economic impact.
17) Recommends a means of preventing the corrosion process.
18) <i>Discusses the engineering utility of the magnitude of the corrosion current in a given engineering application.</i>

Table 3. Performance Criteria. Only about 50% of the students met the italicized performance criteria.

Performance criteria

We tested the students' skills against the 18 performance criteria (PC) shown in Table 3 above. The criteria tested their ability to deal with concepts in math, science, engineering and technology. The criteria were evaluated by grading a written lab report for each student. Each of the questions was designed to test a performance criterion. There was no significant difference between the performance of CE learners and AC learners. Both groups met or failed to meet the criteria in equal proportions, possibly suggesting that approach that we used in the module reached students of diverse learning styles equally well (or equally poorly).

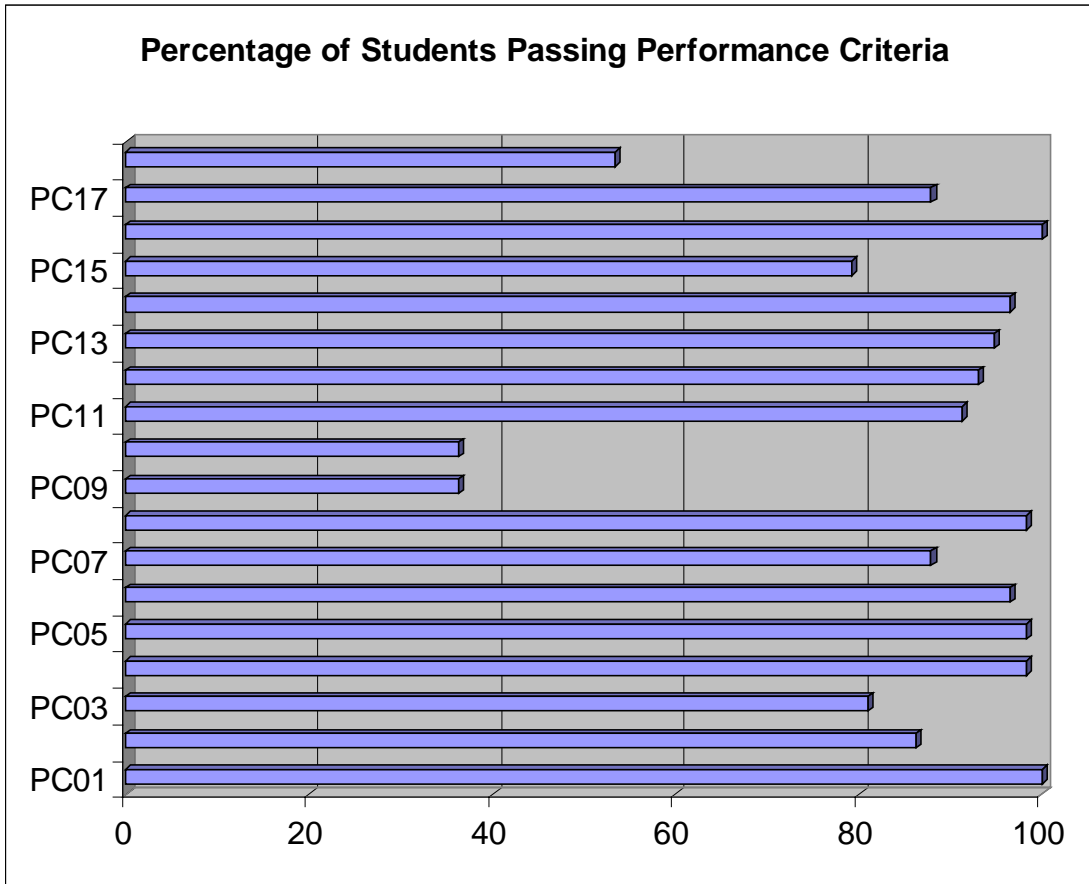


Figure 4. Percentage of students satisfying Performance Criteria (PC) 1-18.

As shown in Figure 4, roughly 80% or more students were able to meet 15 of the 18 criteria. Incidentally, the data in Figure 4 comes from 75 students, evaluated independently of the surveys mentioned in the previous section. We note that the majority of the PC's test specific skills (such as plotting data, PC 14). One would expect that the majority of junior and senior engineering students would be capable of basic math and engineering science skills. Some criteria, however, test the students' knowledge of the specific application of corrosion. Because this is their only course in materials engineering, we may be able to conclude that the module

was effective in imparting knowledge specifically about corrosion. Because we did not conduct an evaluation of their performance on the criteria before the lab, we cannot soundly conclude that the module in fact assisted these students to develop some of the skills that were tested in the PC's.

We note that roughly 50% of the students did not meet criteria 9,10 and 18. These criteria deal with the applying a principle normally learned in one course to an unfamiliar application. Specifically, criteria 9 & 10 dealt with the ability to apply statistical principles to "real life" data. Criterion 18 dealt with the ability to apply engineering concepts to a practical application. One *would* expect a group of junior and senior engineers to meet these criteria as well.

The preliminary data from our study enforces that idea that students are often not able to apply concepts to situations that are out of the context of the learning the concept. As a result, there is a need for learning opportunities to cross the artificial boundaries between disciplines. In other words, opportunities that allow students to integrate mathematics with engineering applications are needed to strengthen students' ability to apply their knowledge.

V. Conclusions

We designed a module on corrosion to reach students of diverse learning styles. We evaluated the performance of 75 students against a set of 18 criteria addressing math, science, engineering and technology skills. The learning styles of 27 students was evaluated and tracked during the lab. The data indicate that approximately 80% or more of the students completing the lab module were able to meet performance criteria relating to science, and mathematics, regardless of learning style. Although it is likely that the students possessed the basic mathematic skills before completing the module, we suspect that completing the module was responsible in helping students develop a better understanding of the corrosion process. The data also indicate that although students can demonstrate an understanding of science and mathematical principles, they may not be able to apply these principles to a technological or engineering application. Students would benefit from learning opportunities that allowed them to apply these concepts to "real-world" engineering applications.

VI. Acknowledgements

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LINDA VANASUPA

Linda Vanasupa is a Professor in Materials Engineering at California Polytechnic State University in San Luis Obispo, California. As an undergraduate at Michigan Technological University she studied Metallurgical Engineering (B.S. 1985). She received her M.S. (1987) and Ph.D. (1991) from Stanford University in Materials Science and Engineering. As a faculty member at Cal Poly, she has endeavored to incorporate interdisciplinary approaches within engineering courses like Microelectronics Processing and Electronic Properties of Materials.

HEATHER SMITH

Heather Smith joined the faculty in the Cal Poly's Statistic's Department in 1997 after seven years of consulting to various manufacturing industries and government clients. She holds a M.S. degree in Statistics from Florida State University (1989) and a B.S. in Mathematics from the University of Florida (1986). In coming to academia, her goal was to better prepare engineering students for experimental work in their respective fields. She has informally team taught several engineering labs, emphasizing the use of statistical tools to decide logical courses of action. She continues to work as a consultant to a variety of engineering and science fields.

JEFF JONES

Jeffrey E. Jones is a licensed Professional Civil Engineer. In addition to being the Division Chair of the Engineering & Technology Division at Cuesta College in San Luis Obispo, California, he has taught several engineering science courses. He has over 10-years experience in teaching, bringing multi-media courses to the community college. Prior to becoming a teacher he spent 10 years as a structural engineer. He earned his M.S. degree in Civil Engineering from San Jose State University.

BLAIR LONDON

Blair London is also a Professor in Materials Engineering. He received his B.S. in Materials Engineering from Drexel in 1981. His M.S. (1983) and Ph.D. (1986) degrees are in Materials Science and Engineering from Stanford University. He joined the Cal Poly faculty in 1993 after seven years of experience in the aerospace industry. During his time at Cal Poly he has developed several effective teaching methodologies for the laboratory setting.

LANNY GRIFFIN

Lanny Griffin is an Associate Professor in Materials Engineering at Cal Poly. He holds a joint appointment in Cal Poly's Bioengineering Program. He received his B.S. in Mechanical Engineering in 1992 from Cal Poly. In 1996 he received a Ph.D. in Materials Science and Engineering from the University of California at Davis. He is active in researching fatigue and fracture of calcified tissue and finite element and constitutive modeling of complex materials systems.

KATHERINE C. CHEN

Katherine Chen joined Cal Poly's Materials Engineering Department as an Assistant Professor in 1999 after three years at Los Alamos National Laboratory. She earned her Ph.D. from the Massachusetts Institute of Technology in Materials Science (1996) and B.S. and B.A. degrees (1990) from Michigan State in Materials Science and Engineering and Chemistry, respectively.

DAVID NIEBUHR

David Niebuhr graduated from Cal Poly's Materials Engineering Department in 1993. He earned his Ph.D. in Materials Science and Engineering in 1997 from the Oregon Graduate Institute of Science and Technology. His area of expertise is tribology and wear. He joined Cal Poly's Materials Engineering Department as an Assistant Professor in 1999.

APPENDIX

QUESTIONS		Learning Style (Percentage)						Learning Style Means	
		Concrete (n=14)			Abstract (n=13)			Concrete	Abstract
		Agree	Neutral	Disagree	Agree	Neutral	Disagree	Mean Score	Mean Score
1) I enjoy learning about different subjects on my own.	Pre	78%	14%	7%	64%	29%	7%	3.93	3.64
	Post	100%	0%	0%	69%	31%	0%	4.10	3.63
2) I am comfortable with using math, science, and engineering techniques to solve problems.	Pre	100%	0%	0%	86%	14%	0%	4.64*	4.14
	Post	91%	8%	0%	100%	0%	0%	4.25	4.38
3) For me, studying in groups is better than studying alone.	Pre	57%	43%	0%	43%	43%	14%	3.79	3.36
	Post	64%	33%	0%	62%	31%	6%	3.65	3.75
4) I believe that computers should be used in the classroom on a regular basis.	Pre	50%	36%	14%	36%	50%	14%	3.57	3.29
	Post	84%	8%	8%	56%	25%	13%	3.55	3.50
5) I can learn better when instructors use various technology in the classroom	Pre	78%	14%	7%	50%	50%	0%	3.79	3.64
	Post	75%	25%	0%	50%	50%	0%	3.75	3.63
6) I am comfortable with giving oral presentations on the work I have done.	Pre	43%	29%	28%	29%	29%	43%	3.07	2.71*
	Post	33%	50%	16%	38%	50%	13%	3.15	3.63
7) I am comfortable with providing a written report on the work I have done.	Pre	93%	7%	0%	57%	36%	7%	4.00*	3.64
	Post	67%	33%	0%	62%	38%	0%	3.60	3.88
8) Generally, I am comfortable with communicating my ideas to others.	Pre	85%	14%	0%	71%	21%	7%	4.00	3.71
	Post	83%	17%	0%	88%	13%	0%	3.95	4.13
9) I am comfortable with working with students who are of a different race, ethnicity, or culture.	Pre	93%	0%	0%	86%	14%	0%	4.21	4.43
	Post	91%	8%	0%	100%	0%	0%	4.15	4.63
10) I come to group meetings prepared	Pre	79%	21%	0%	78%	21%	0%	4.07	4.00
	Post	100%	0%	0%	88%	13%	0%	4.00	4.25
11) In my group, I listen to the ideas of others with an open mind.	Pre	100%	0%	0%	85%	14%	0%	4.36	4.07
	Post	100%	0%	0%	100%	0%	0%	4.25	4.38
12) During group time, I constructively criticize ideas not people.	Pre	79%	21%	0%	78%	21%	0%	4.07	3.86
	Post	75%	25%	0%	75%	25%	0%	3.70	4.13
13) I do not dominate during group time.	Pre	71%	29%	0%	72%	29%	0%	3.93	4.00
	Post	69%	25%	6%	72%	29%	0%	3.55	3.50
14) I take responsibility for the team's success.	Pre	53%	29%	29%	43%	36%	14%	3.29	3.39
	Post	83%	8%	8%	75%	19%	6%	3.90	3.88
15) I am aware of other team members' feelings.	Pre	85%	14%	0%	71%	29%	0%	4.07	3.93
	Post	92%	8%	0%	75%	19%	6%	4.00	3.63
16) I understand what my team expects me to do.	Pre	93%	7%	0%	100%	0%	0%	4.00	4.21
	Post	75%	25%	0%	94%	0%	0%	4.00	3.63
17) As a team, we have developed ways to reach consensus.	Pre	50%	43%	0%	57%	43%	0%	3.36	3.79
	Post	58%	25%	8%	69%	25%	0%	3.30	3.88
27) In my opinion, lecturing on a subject is boring.	Pre	21%	29%	50%	28%	57%	14%	2.71	3.21
	Post	42%	0%	42%	50%	38%	0%	2.60	3.38

*Significant difference at .05 level.