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An Integrated Laboratory Vs. A Traditional Laboratory, Is there a difference?

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Abstract

Do integrated, graphics-rich laboratories foster enhanced learning when compared to traditional laboratory experiments? More and more, higher education emphasizes the need to utilize integrated approaches to learning. We performed a comparative study involving over 500 engineering students. Using corrosion of metals as our subject we performed two sets of experiments. In the control lab, students answered questions and performed traditional, structured experiments. Our modified lab integrated science, engineering, and math and utilized multi media and colorful graphics. More importantly though, it required the students to problem solve and work through a real engineering challenge. The results are discussed and include a statistical analysis of the data. The implications of the results will shape the direction in which the lab evolves and will shape future experiments in the department's curriculum.

1. Introduction

Engineering education is in the midst of a renaissance as the new millennium has arrived. More and more universities are recognizing that the traditional approach of teaching basic courses (math, physics, chemistry) as separate, isolated disciplines is affecting the numbers of students who remain in engineering majors and graduate as engineers. For example, calculus is a freshman course, yet the application of calculus principles may not come until late sophomore or junior year. This leaves the student to feel that calculus is unimportant and strictly a "weeder" class due to the high failure rate. At the Colorado school of Mines, the integration of courses is taken one step further where integrated laboratories replace traditional laboratories in electrical circuits, fluid mechanics, and stress analysis.[1] The laboratory experiments are designed to combine math and physics and require students to build and analyze small, laboratory scale systems. Creating integrated labs have been the premise of many other studies in both engineering and multidisciplinary education.[2,3,4]

The need to integrate and foster innovative teaching ideas was recognized by the National Science Foundation (NSF) in the early 90's. In 1993 the NSF sponsored a seven school education coalition.[5] The focus of this coalition was to develop curricular change that integrated the traditional fundamentals in mathematics and science plus emphasized problem solving and

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design. NSF also emphasized the need to improve the learning experience in the freshman and sophomore years.

Traditional methods of engineering education often involve a piece meal approach where the fundamental topics such as math, statistics and chemistry are taught as separate, stand-alone courses. In some ways this is like eating a pie one ingredient at a time, where the seemingly unrelated topics are devoid of integrative synergy.[6] And since these support courses are taken early in a student's career it becomes more crucial to capture their attention and create enthusiasm, lest we see yet another change of major request. This is not to say that the fundamentals are not important nor are we here to entertain the students, rather we propose an approach that gives the student an appreciation for real world problem solving and the importance of fundamentals.

The integration of science, math and engineering is not a new concept. In a study performed by the Board of Engineering Education under the National Research Council several key points were listed:[7]

a) Undergraduate education must include exposure to "real" engineering that is interdisciplinary, hands-on, and industrially relevant.

b) A strong knowledge of *how* to learn must be instilled during the educational process.

c) More of an emphasis on engineering design (creative synthesis) while maintaining the engineering science (analysis)

Integrated labs have received much attention and research and integration is part of the new engineering education paradigm where subject matter, concepts, principles and current issues are melded together into a single learning experience.[8] The question arises does this integration make a difference in student learning? Does multi-media and an emphasis on design (compared to simple cause and effect problem solving) also aid in student learning? Intuitively one would think a lab experience that illustrated real world applications and included multi-media would garner more interest (and thus retention) than a "traditional" laboratory, which contained canned experiments and predictable outcomes. Determining and measuring student learning is not trivial and this study only scratched the surface of the larger field of learning outcomes and assessment. *Our goal was to determine if students learned more after we modified an existing laboratory.*

The integrated labs premise of this study came when the authors participated in an NSF sponsored proof of concept project to modify one laboratory experiment in a sophomore level materials engineering course.[9] The project chooses a corrosion of metals laboratory. A "traditional" lab experiment, which required measurement, observation, and conclusion, was modified to an integrated corrosion lab. The integrated lab had all the attributes of the traditional lab except it also included statistics and design (creative synthesis) and incorporated multi-media in the form of an interactive CD-ROM. (The format of both new and old labs is explained later).

Some of the educational objectives of the new integrated lab included:

- Building life-long learning skills
- Enhance student thinking skills
- Encourage students to make a connection between several disciplines
- Improve retention within the college of engineering

We wanted to determine if there was a difference between the performance of students conducting the original (traditional lab) and those conducting the modified (integrated) lab. To do this we developed a quiz that included 10 multiple choice questions and a design question. This quiz was given to 527 students where roughly half performed the laboratory the original or "traditional" way and the other half performed the integrated, multi-media enhanced laboratory.

The laboratory is one of eight experiments that cover basic material science and engineering concepts in a one unit, 10 week quarter and is designed to compliment a three unit *Introduction to Materials Engineering* course. The laboratory class is a mix of several engineering disciplines and is the first exposure to materials engineering concepts for almost all of the students.

Several questions about this study will be answered and include:

1. Is there numerical evidence to suggest students learn more in the integrated lab?
2. Does the instructor influence the student's performance?
3. Does multi-media vs. simple written directions improve retention?

II. Experimental

Over the course of 2 years the performance of 527 students was measured using a standardized test given at the end of the quarter. 268 students performed the experiment the standard way (traditional) and 259 performed the experiment utilizing the new integrated and interactive approach, which gave roughly a 50-50 distribution. A brief description of each lab is given along with the quiz and statistical analysis performed.

Traditional Experiment

The original corrosion lab was developed over 15 years ago and had undergone some minor revision over the years.[10] The lab consisted of three parts, which included observation of steel corroding in various media, measurement of corrosion potential (volts) between a standard graphite electrode and various metals (Al, Fe, Cu, etc.) and measurement of corrosion rate as a function of cathode / anode ratio. This sequence of presentation from simple to more difficult was retained in the "Integrated" lab.

Part I.
The students were required to observe four flasks that contained immersed steel coupons with an equal time of exposure. The conditions were:

1. Plain tap water (control)
2. Tap water with 2% K_2CrO_4 (corrosion inhibitor)
3. Boiled tap water

4. Steel in plain tap water attached to a sacrificial anode of zinc.

Part II.
The corrosion potentials were measured between graphite and several commercially pure metals in a simulated seawater environment. From this data the metals were ranked from the least active (inert) to the most active and compared to the order of a published galvanic series.

Part III.
The corrosion rate of zinc was measured when a galvanic cell (two metals connected electrically and immersed in a salt water solution) was created between zinc and copper. The corrosion rate would increase when the copper cathode increased in size. This demonstrated the importance of the ratio of cathode to anode area and its influence on corrosion rate. Essentially the students would measure values, record them and then make conclusions about the data. A worksheet would also be completed that required definitions and the answering of two corrosion related questions.

Integrated Experiment

The revised experiment integrated statistics, math and design with the corrosion concepts.[11] The three parts from the original lab were retained, but modified to foster more creative thinking and problem solving skill development. The 3 parts again included observation, measurement and calculation, but now emphasized statistical concepts and design challenges.

Part I.
The observations were recorded and then students were asked to explain why the samples appeared the way they did. This was a standard cause and effect exercise that we felt should remain unchanged from the original lab. Again, there was an emphasis on why and how the behavior occurred.

Part II.
Measurement of corrosion potential was performed on several alloys relative to the standard graphite electrode. The metals tested were engineering alloys instead of pure metals. The potential was measured in simulated sea water for comparison to the galvanic series. Multiple measurements of each alloy were taken in a random order to demonstrate repeatability.

The modified lab integrated statistics as a major component. The students were asked to randomize their measurement order and to repeat similar measurements in order to accrue more than a single data point. The students were asked to differentiate the accuracy and precision of the experiment. The concept of margins of error was introduced and included determination of a *real* statistical difference. In addition, Part II required students to extrapolate their findings to solve an engineering problem. These design problems required the student to look beyond the immediate subject matter and draw upon experience and common sense. Two of the question from Part II appear below:

"Based on the measurements you took, which metal would you recommend as a candidate for the body of a pacemaker?" and "What other factors besides corrosion are important in selecting the material for the pacemaker body?"

Unlike the traditional laboratory these questions gave the students some latitude in their answers and better simulated a real-world type of problem.

Part III.
In Part III the effect of changing relative cathode to anode area is demonstrated. This concept was done in the original lab as it was a powerful concept. For example, a small scratch in the lining of a tank (holding acids, caustics, etc.) can yield a large rate of corrosion and premature failure if unchecked. The students also see how corrosion rate reaches equilibrium after a short time (< 5 minutes). They also perform calculations and determine how they may create a battery simply by connecting a series of galvanic cells.

Overall both labs gave the students a good overview of the mechanisms and importance of understanding corrosion. But the integrated lab was developed so that students would see the interconnection between corrosion, math and statistics to solve engineering problems.

Assessment

To assess student performance a multiple choice quiz was given at the conclusion of the course. The quiz consisted of ten questions that were divided into 5 questions pertaining to basic statistical analysis into 5 questions pertaining to corrosion principles. In addition a design question was given that required the students to synthesize the concepts learned.
All students took the same quiz, which was given with the final. As a result the time between lab completion and quiz varied between 1 and 9 weeks. (Recall the lab experiment was one of eight taught over a 10 week quarter in a round-robin format). Lab sections from six different instructors were included in this study. The quiz was graded as 20 points with each multiple choice question counting as 1 point. The design question was worth 10 points and graded as 0, 4, 7 or 10, depending on the level of explanation. This 4 tier system minimized the effect of subjective grading. Sample questions are listed below.

<u>Statistics example</u>

Experimental error:

a. Can always be measured
b. Is best defined as slight differences between repeated experimental tests
c. Can be eliminated if proper lab protocol is implemented
d. Is always evident in a real system
e. All of the above
f. b & d

<u>Corrosion example</u>

Cathode size:

a. Will determine corrosion potential
b. Has no effect on corrosion rate
c. May change as corrosion occurs
d. Should be maximized to prevent corrosion
e. None of the above

<u>Design question</u>

Explain how a practical system for preventing corrosion may be created given that you have a steel component that can tolerate zero weight loss during its life. (Life being defined as 1 year under atmospheric conditions) (10 points).

The results were compiled and analyzed using a general linear model in Anova. P values were calculated, where a value below 0.05 was considered confirmation of our null hypothesis.

III. Results

Without looking at any of the data and only observing the students as they performed the old and new laboratory it became apparent that the integrated approach had generated greater enthusiasm in the students. This informal conclusion comes following teaching the course a dozen or so times over the past 4 years, where the modified lab came into being 2 years ago. These sentiments were shared by my colleagues who had also taught the lab the old and new way.

The quiz results are broken down into 4 dot plots shown in Figures 1 through 4. Figure 1 illustrates the results of the statistics multiple choice questions, Figure 2 the results of the corrosion multiple choice questions and Figure 3 is the design question results. Figure 4 combines the total scores received on the quiz. In all four figures it is clear that the students taught using the new integrated lab scored higher than their peers performing the old lab. Table 1 summarizes the numerical results of the Anova analysis and it is noted that $P < 0.0001$ for all four analyses.

Statistics		Corrosion		Design		Total	
New	Old	New	Old	New	Old	New	Old
2.9	1.2	3.2	2.2	6.8	4	12.8	7.4
$\Delta = 1.7 \pm 0.2$		$\Delta = 1.0 \pm 0.2$		$\Delta = 2.8 \pm 0.5$		$\Delta = 5.4 \pm 0.6$	
Above values are the numerical point scores for the new and old lab method							

Table 1. Numerical scores for each part of the assessment quiz. Note: Statistics and Corrosion are out of 5 points, Design is out of 10 points and the total is out of 20 points.

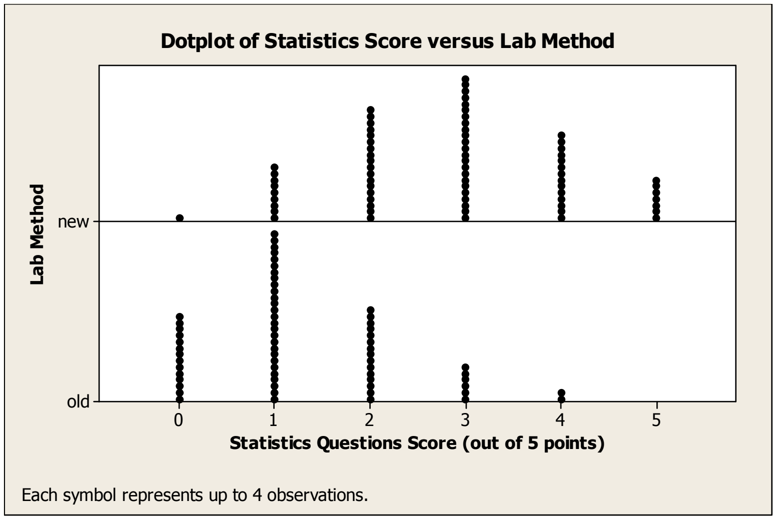

Figure 1. Dotplot of student performance on statistics questions

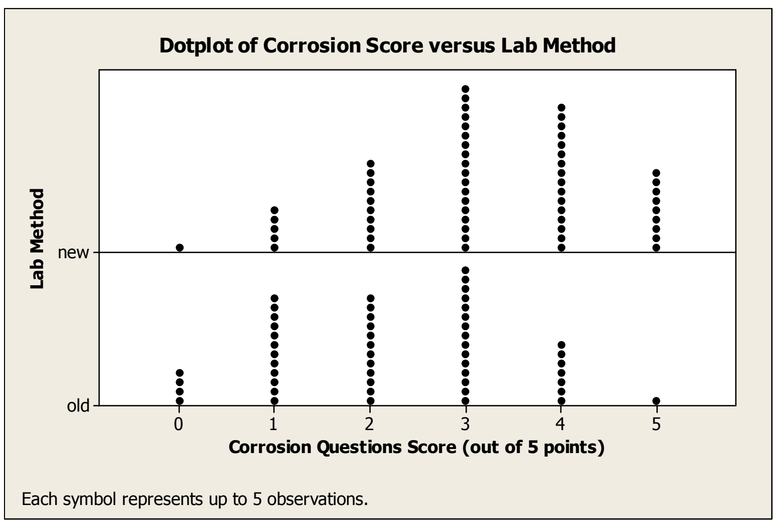

Figure 2. Dotplot of student performance on corrosion questions

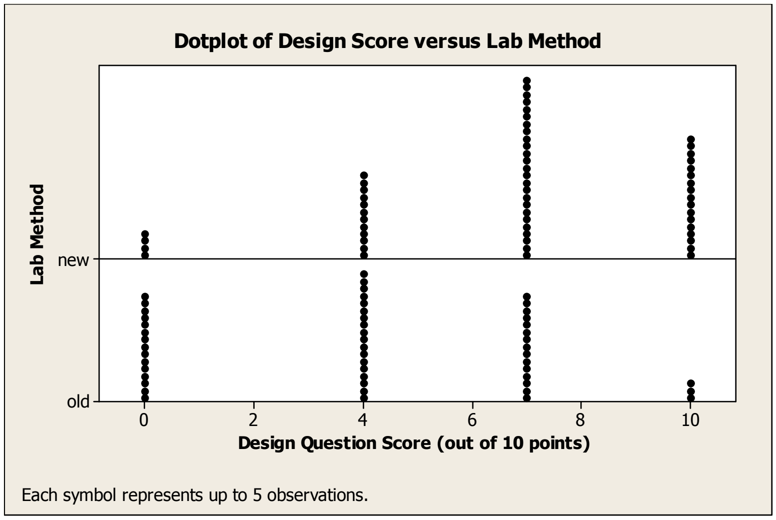

Figure 3. Dotplot of student performance on design question.

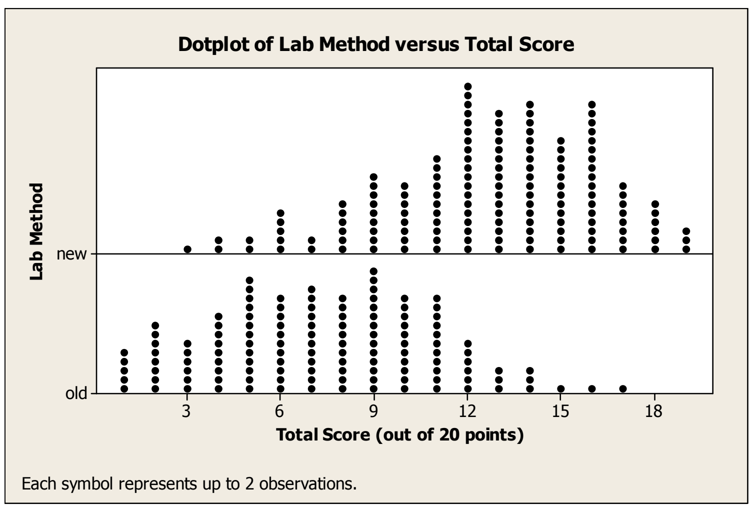

Figure 4. Dotplot of total score on Assessment.

IV. Discussion

The total score of the assessment was separated into 3 parts so that a more thorough analysis could be performed. We looked at the improvement of statistical knowledge, corrosion knowledge and design ability in the assessment.

Statistics Questions

Questions 1 through 5 were based on the statistics covered in the experiment and came directly from the reading material. The traditional lab had no mention of statistics so the only knowledge the student would possess would have come from other classes. We expected the new lab to perform significantly better on these five questions, which was confirmed by an average score increase of 1.7 points $\pm$ 0.2 points, a 145% improvement over the old lab results. In fact, the average score from the old lab on these questions was only 1.2 points $\pm$ 0.2 points out of five, which puts the score at what one would expect if one just randomly guessed. The average score from the new lab on these questions was 3.7 points $\pm$ 0.2 points out of five, indicating a result that is more likely attributable to student learning than random guessing. This finding may seem obvious, but we wanted to know if the integration of statistics into the lab was actually retained at the conclusion of the course. Three of the questions required basic understanding of replication and experimental error. Based on the poor performance by the old lab students, it seems clear that an appreciation for sources of variation in an experimental setting was not grasped by these students. We found this fundamental oversight disturbing. However, it was encouraging to see that upon completion of the new lab, students better understood statistical principles and that they retained what they learned.

Corrosion Questions

Questions 6 through 10 were based on corrosion concepts that were covered in both labs. Unlike questions 1 through 5 all of the corrosion questions could have been answered by completion of either lab. Thus, these are a measure of how well the information was retained after executing the experiments. On average the students scored one point higher or a 45% improvement. Factoring out the statistics, the new lab combined problem solving, design and an interactive CD-ROM that students were given the week prior to the lab to explain basic corrosion concepts. Informal surveys suggested that greater than 50% of the students reviewed the CD before coming to lab. The CD utilized streaming video and sound to illustrate key corrosion concepts. Anecdotally the CD was well received by the students, but there is no numerical data to confirm its effectiveness per se. We make the assumption that it added to the overall learning experience of the students and was reflected by their overall higher scores on the assessment. This improvement was encouraging given that the quantity of corrosion information presented was not increased, but rather it was made more palatable for the students.

Design Question

In the design question the student was faced with suggesting a practical solution for a corrosion system. The question was left intentionally vague and required students to make assumptions, which was given in the instructions. The grading of this question was challenging making the 4 tier scale critical. If the student had no idea or did not reach some threshold of understanding they were given a 0/10. If they made assumptions and provided a reasonable answer they received 10/10. The grade of 4/10 or 7/10 was given for less complete answers or answers that were impractical. Since all of the design questions were graded utilizing the same criteria, the imperfect nature of the question could be factored out.

Seven different instructors taught this lab during the assessment, with varying number of students assessed between instructors. Three of the instructors taught the lab both the old way and the new way during the assessment and represented roughly half the students. Looking at the data and performing an analysis of score as a function of instructor we concluded there was only a negligible difference ($P > 0.09$), where the difference on the total score was 1.0 point $\pm$ 0.7. This is also encouraging as it supports the merit of the experimental improvement.

V. Conclusions

The objective of the study was to confirm that the innovated lab fostered learning, retention and an overall more positive experience during exposure to corrosion concepts. Despite the limitations of the study we feel strongly that this objective was achieved. The experiment re-write was an improvement over the old, traditional corrosion experiment that had been used for many years. The assessment data and anecdotal evidence strongly support this. To make a better argument though all of the instructors should have taught the lab the old way and the new way. This was not always practical and seen as a limitation of the study. However, only negligible evidence supports the premise that the instructor had an effect on the outcome. Also, the authors feel the assessment should have been longer, perhaps 20 multiple choice questions and 2 or 3 design questions. Following this study the lab was improved yet again as part of a continuous improvement process which we feel would have made the differences seen in this study even more dramatic

VI. Acknowledgments

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VII. References

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