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Effect of Freshman Chemistry on Student Performance in Sophomore Engineering Courses

Michael A. Collura
University of New Haven, mcollura@newhaven.edu

Shannon Ciston
University of New Haven, sciston@newhaven.edu

Nancy Ortins Savage
University of New Haven, nsavage@newhaven.edu

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AC 2011-2374: EFFECT OF FRESHMAN CHEMISTRY ON STUDENT PERFORMANCE IN SOPHOMORE ENGINEERING COURSES

Michael A. Collura, University of New Haven

MICHAEL A. COLLURA, Professor of Chemical Engineering at the University of New Haven, received his B.S. Chemical Engineering from Lafayette College and the M.S. and Ph.D. in Chemical Engineering from Lehigh University. He is currently serving as the Director of the Multidisciplinary Engineering Foundation Spiral Curriculum. His professional interests include the application of computers to process modeling and control, engineering education research and reform of engineering education

Prof. Shannon Ciston, University of New Haven

Shannon Ciston is an Assistant Professor of Multidisciplinary Engineering at the University of New Haven in Connecticut. Her background is in Chemical Engineering, with degrees from Northwestern University (Ph.D.) and Illinois Institute of Technology (B.S.). Dr. Ciston's research interests are in two main areas: Engineering Education (including student experience, attitudes, and perceptions) and Sustainability (including impacts of the Chemical and Energy industries on water resources).

Dr. Nancy Ortins Savage, University of New Haven

Nancy Ortins Savage, PhD. is an assistant professor in the Department of Chemistry and Chemical Engineering at the University of New Haven. Dr. Savage received her B.S. in Chemistry from Rensselaer Polytechnic Institute and her PhD. in Chemistry from The Ohio State University. Her research is in the development of new metal oxide-polymer composites and their application as gas sensors. She is also the director of the Summer Institute for Young Women, a STEM camp for middle school girls which takes place at the University of New Haven each summer.

Effect of Freshman Chemistry on Student Performance in Sophomore Engineering Courses

Abstract

The role of first year chemistry courses in engineering programs varies somewhat across programs and disciplines. Clearly most engineering majors will encounter chemistry topics of a general nature in some of their upper-level course work. The purpose of requiring chemistry in the first year, however, goes well-beyond learning chemical concepts. As a quantitative science, chemistry requires the use of math, principally algebra, on a regular basis in solving various problems. Students should gain an appreciation of the importance of units in solving problems should come to understand the difference between implicit and explicit properties and should develop other quantitative skills. Depending on how it is taught, chemistry can provide students with a wide range of opportunities to hone skills that will be required in their engineering courses. In discussions with students and even with many faculty, the role of chemistry is often viewed narrowly in terms of the chemistry topics alone. The purpose of this study is to explore how the number of chemistry courses taken and the performance in freshman chemistry affects performance in early engineering courses.

Engineering students at the University of New Haven have different requirements for freshman chemistry depending on their particular discipline. All engineering students are required to take at least one freshman chemistry course. Students in chemical and civil engineering are required to take two, students in mechanical and system engineering have an option of biology or a second course in chemistry and students in electrical and computer engineering take only one freshman chemistry course. All engineering students take a sophomore engineering course, Introduction to Modeling of Engineering Systems, which includes topics drawn from electric circuits, mass and energy balances and force balances. The course is designed to help students develop an organized approach to solving problems and uses a conservation and accounting approach to provide a broad framework for the diverse topics. This course provides an opportunity to explore how their freshman chemistry background prepares studcents for engineering coursework.

This study examines the impact of having one or two freshman chemistry courses on student performance in the first sophomore level engineering course. The methods used include standard statistical techniques, such as analysis of variance, correlation (eg., Pearson) and t-tests across groups.

Introduction

Since the middle of the 20th century American engineering education has stressed the importance of math and basic science as a foundation for engineers. Recommendations from the Grinter report[1] resulted in most engineering programs requiring at least one semester of freshman chemistry with many programs adding a second required course. During the past two decades, universities have experimented with various curricular models, including the way in which chemistry was incorporated into the program. In the 90's, Drexel[2] pioneered a highly integrated curriculum which incorporated chemistry into larger modules with math and engineering content. The time devoted to chemistry in such models was often less than in traditional curricula. As many other demands were made to add content, some programs attempted to reduce the chemistry credits by creating "chemistry for engineers" courses. Some examples include courses for specific majors [3,4] while others are application-oriented, such as having a focus on materials[5]. In most studies of the role of chemistry in engineering education, the emphasis is on the chemistry content.

In discussing curricular issues with other faculty it has become clear that faculty in most engineering areas view chemistry from a content-oriented perspective and may not fully appreciate the role of these courses in the overall development of their students. The authors believe that the role of chemistry is much broader than developing an understanding of specific chemical principles. Freshman chemistry provides an opportunity for students to apply math to solve practical problems, to wrestle with systems of units and to develop problem-solving skills. Particularly for students who are not at the top of their class, the freshman chemistry classes are a key building block in developing their quantitative abilities. The goal of this study is to shed light on the role of freshman chemistry courses in helping students succeed in engineering courses typically taken in the sophomore year. In some cases these classes, such as statics and strength of materials, may not appear to include content that relates directly to topics in chemistry. The quantitative skills developed through the study of chemistry, however, are very important in preparing for these engineering courses.

Description of Courses Relevant to the Study

All engineering students at the University of New Haven take at least one chemistry course in their first year, CH115, General Chemistry I. This is a traditional course, part of a 2-course sequence similar to those found at most universities. Students in chemical and civil engineering are required to take a second first year chemistry course, EAS120 Chemistry with Application to BioSystems. Note that the prefix EAS stands for "Engineering and Applied Science". EAS120 was specifically developed for engineering students, and was designed to integrate some relevant biological science concepts into the existing General Chemistry II course[6]. The biological concepts are examined from a chemistry perspective rather than being treated as they would in a traditional biology course. EAS120 includes most of the topics found in a traditional General Chemistry II course but applies these concepts to biological applications in the lecture and lab part of the course. Examples of course topics include: chemical reactions and their place within biological systems, kinetics of inorganic enzymes and metabolic pathways, acid-base chemistry including the effect of pH and buffers on blood, acid/base behavior of amino acids, intermolecular forces in macromolecules, and determination of biochemical oxygen demand.

Students in mechanical and system engineering have the option of taking this course or a biology class. Electrical and computer engineering students do not take a second chemistry course.

EAS211 Introduction to Modeling of Engineering Systems is a required course for all engineering students taken in the first semester of the second year. Details of the course may be found in a previously published reference[7]. EAS211 introduces students to the modeling of simple engineering systems in different fields using the balance principle and empirical laws. The course presents the modeling process to solve problems that concern conservation of mass, charge, linear and angular momentum and energy, introducing such concepts as Kirchoff's current and voltage laws, linear momentum in fluids, applications of the energy equation in thermodynamics, heat transfer and fluid flow problems. In addition to the use of conservation or balance principles, several other common themes provide a unifying construct for the varied topics. These include the development of an organized approach to solving problems, the use of common computer tools such as spreadsheets and appreciating the complexity of concepts that converge in realistic problems.

Although EAS120 is somewhat unique to our university, it fills the same role as a second general chemistry course would at most universities. Problem-solving skills and calculations included in EAS120 are the same as would be found in a traditional General Chemistry II class. Similarly, EAS211fills the role of a first course in an engineering major, such as statics/strength of materials, mass and energy balances or electric circuits. In fact, EAS211 includes topics typically found in all of these classes. The primary difference is the emphasis on a common framework for developing the equations which model the engineering processes – mass, momentum, energy and charge balances. Just as in the traditional courses, students must develop organized problem-solving skills and must deal with more complex situations than they encountered in their science courses.

In addition to chemistry, engineering students typically study physics. In most programs, the physics courses taken by engineers are calculus-based, and usually have a prerequisite of Calculus I. A national trend in recent years is that entering students often require a pre-calculus course in their first semester. At the University of New Haven, the engineering curriculum was structured to place the physics sequence in the second year to assure that students will have the proper math background for the calculus-based physics sequence. In addition, the common sophomore engineering course (EAS211) discussed above was designed to integrate with a physics course taken simultaneously. Thus the students in this study were generally taking physics concurrent with the sophomore engineering course. It is recognized that many engineering programs may require physics in the first year, and thus the students complete a physics course prior to their first sophomore engineering course. Although such a course may provide a similar effect, this study did not investigate the effect of a freshman physics course.

Analysis and Results

During the fall 2010 semester about 75 students were enrolled in the 4 sections of EAS211. About 25 of these students were excluded from the study due to various issues in their coursework. Many of them were transfer students or students with a significant amount of Advanced Placement credit, including freshman chemistry. Some students were behind in either math or introductory engineering classes. The remaining 50 students were consistent in the sequence of courses taken during their first year: 22 had completed a single freshman chemistry course (CH115) and 28 of them completed both CH115 (General Chemistry I) and EAS120 (our version of General Chemistry II). Table 1 shows some descriptive statistics for the students in the study. There is no statistical difference in the mean gpa and the mean calculus I grade between the groups, as shown by the values of the T-Test probability (p). On average, the chemistry grade for the first group (single chemistry course) is slightly lower, although the difference is not statistically significant.

Table 1 – Comparative Characteristics of Student Groups in Study

		gpa		Chemistry I grade		Calculus I grade	
	Num	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Group 1 – 1 CH course	22	3.33	0.43	2.7	1.0	3.1	1.0
Group 2 – 2 CH courses	28	3.31	0.43	3.0	0.92	2.9	1.3
T-Test statistic (p)		0.86		0.29		0.51	

To best assess the effect of taking a second chemistry course on EAS211 performance the students were grouped by gpa range into 3 sets. Cut points were selected to create approximately equal sets of low, middle and high gpa students. Table 2 shows the data for the groups along with some descriptive statistics.

Table 2 - Characteristics of Students in Study Grouped by gpa

gpa group	num CH courses	Number students	avg gpa		Chem 1		Calc 1		Chem 2
				p	grd	p	grd	p	grd
Low (< 3.21)	1	7	2.8	0.84	2.2	0.70	2.2	0.59	
	2	10	2.9		2.3		2.1		2.3
Mid (< 3.538)	1	8	3.4	0.55	2.5	0.12	3.4	0.57	
	2	9	3.4		3.0		3.0		3.2
High (> 3.538)	1	7	3.8	0.87	3.8	0.95	4.1	0.35	
	2	9	3.8		3.8		3.8		3.9

T-Tests (p values in table) were performed to assess if there were significant differences between the students with 1 vs 2 freshman chemistry courses in each gpa group. No significant differences were observed in the gpa for each paired set of students. The lowest gpa groups showed very similar grades in Chemistry I and Calculus I. The top group showed very similar chemistry grades, but a slightly lower math grade for the group with 2 chemistry courses. The middle gpa group showed a bit more difference in chemistry and math grades. The relatively small size of each group leads to this level of variation.

To assess the performance in the first sophomore engineering course, EAS211, several measures were used. A "readiness" quiz (Quiz 0) was given within the first week of the class to assess student mastery of basic topics needed for the class. This quiz included topics such as unit conversions, mixture composition, balancing chemical equations, flow relationships, force, stress/strain concepts, Ohm's law, Kirchhoff's laws and electrical power. Students had encountered these topics in first year engineering classes or in chemistry courses. The final grade in EAS211 was a second metric used in the study. The authors were concerned, however, that variations due to student ability and attitude would be significant. To compensate for these factors, the difference between each student's grade in EAS211 and his/her cumulative gpa for the term prior to taking EAS211 was used. On average, students' grades in EAS211 were about ½ a letter grade lower than their cumulative grade point average (gpa) prior to taking EAS211. The range of values was from a low of -2.21 (more than 2 letter grades below gpa) to + 0.71 (about 3/4 of a letter grade above gpa). Thus to minimize variations due to student effort and ability, this difference was used to investigate the effect of taking a second chemistry course. Since both gpa and course grades are on a 0 to 4.0 scale, the grade differential is a useful measure of performance. Analysis of results was done using SPSS and Excel to apply T-Tests for comparison of means between groups and to calculate Pearson Correlation Coefficients to assess correlation between variables. These methods are generally accepted for assessments of this type[8]. Data for the 3 metrics are shown in Table 3 below:

Table 3 - Comparison of Means/ number of freshman Chem courses - grouped by gpa

gpa grp	num CH	EAS211gr	p	Quiz 0	p	differential	p
Low (< 3.21)	1	1.6	0.17	37	0.01	-1.2	0.17
	2	2.1		54		-0.8	
Mid (< 3.538)	1	3.0	0.65	59	0.50	-0.5	0.75
	2	2.8		51		-0.6	
High (> 3.538)	1	3.4	0.44	74	0.92	-0.5	0.33
	2	3.7		75		-0.2	

With the exception of the Quiz 0 grade for the bottom gpa group, the differences in means are not statistically significant at the 95% confidence level. This is primarily due to the relatively small number of students in each sub-group. However, the trends are still interesting and worth further investigation. It appears that the impact of taking a second freshman chemistry course is most pronounced for students in the lowest gpa group, with an improvement of ½ a letter grade for the students with a second chemistry course. It is not surprising that these students performed significantly better on the readiness quiz, however, the magnitude of the differential between the grade in EAS211 and the gpa is quite large.

The differential between EAS211 grade and gpa is negative, meaning that the EAS211 grade is lower than the previous term gpa. Thus a smaller negative number for this metric indicates performance closer to the student's previous level. Students in the middle gpa group show essentially no difference in this metric (0.1). Students in the lowest and highest gpa group who have had two chemistry course show better performance by this metric with differences of 0.4 and 0.3, respectively. Note that a value of 0.3 for this metric would be approximately the difference between a B and a B+.

To further examine the effect of chemistry courses on engineering course grades, correlation coefficients were determined for several paired variables, including the grade in each chemistry class, the grade in calculus I and the gpa. The analysis included the grade in calculus I as an independent variable as a point of comparison. It is widely believed that math skills play a key role in academic success for engineering students. Thus it is useful to view the level of correlation between performance in the engineering course and math as a baseline to which the correlation with chemistry can be compared.

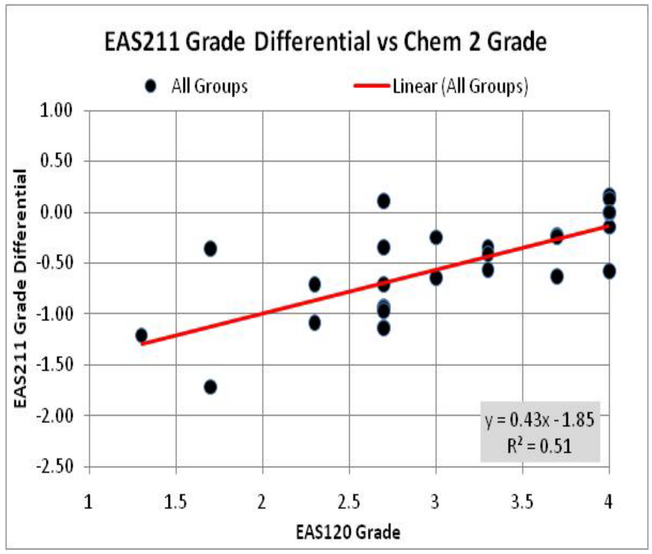
Table 4 – Correlation of Engineering Course Performance to Several Inputs

		Pearson Correlation Coefficients (r)			
Independent Variables	**N**	**gpa**	**EAS211 grade**	**Quiz 0 grade**	**EAS211 grade differential**
gpa	50	1	0.77	0.58	0.42
Calculus I grade	41	0.66	0.65	0.63	0.48
Chemistry I grade	49	0.75	0.58	0.43	0.32
Chemistry II grade	28	0.90	0.89	0.62	0.72
All correlations found to be significant at the 99% confidence level ($p < 0.01$)					

As expected, the grade in EAS211 shows a fairly strong correlation to the gpa and to the grade in calculus I. It shows a somewhat weaker correlation to the chemistry I grade. For the population of students studied, however, the grade in the second freshman chemistry course was the strongest predictor of success in the engineering course. The grade in Quiz 0 (readiness for EAS211) was equally correlated to math and the second chemistry course. It is interesting to note that the grade differential for the engineering class is much more strongly correlated with the second chemistry course than it is with grades in calculus, the first chemistry course grade or the gpa. To put these values in perspective, they need to be viewed differently than we engineers would view correlations among physical phenomena. When viewing sociological relationships, according to Falchikov and Boud[9], a value of 0.5 is considered to imply a strong correlation between the variables, 0.3 is medium and 0.1 is considered low. By this metric, the correlation between EAS211 grade differential and EAS120 grade is quite strong.

Figure 1, to the right, shows a plot of the EAS211 grade differential (EAS211 grade – gpa) vs grade in EAS120 (second freshman chemistry course). Clearly, students found EAS211 to be a difficult course in comparison to courses they had taken in the freshman year. Few students performed as well in EAS211 as they had done previously. Note that the R^2 value for the trendline on the plot is the square of the Pearson Correlation Coefficient presented in Table 4. It is also noted that students who did better in EAS 120, and who are generally stronger students overall, showed less scatter in the grades for EAS211. That is, the stronger students are more consistent, as would be expected.

Figure 1



Conclusions

Student performance in a sophomore engineering class was examined with regard to students' freshman chemistry courses. Weaker students (lowest third by gpa) who had taken two semesters of general chemistry performed somewhat better in the engineering course. Students in the top gpa group also showed a slightly higher performance, while students in the middle gpa group showed little difference. Comparison of means was difficult due to the small number of students in each subgroup. A broader study is needed which collects data across several years in order to provide higher levels of statistical significance.

Correlations between performance in the sophomore engineering course and the grade in a second freshman chemistry course were quite strong. In fact, a stronger correlation was observed for the second chemistry course than for the calculus I grade.

While correlation does not necessarily imply a cause-effect relationship, the authors believe that the applied quantitative nature of the material studied in the second chemistry course, along with an emphasis on units and problem solving, is very useful in developing the skills needed for success in engineering course work. Considering that many freshman engineering students today are not ready for calculus when they enter the university, and thus cannot take calculus-based physics, a two-semester sequence of chemistry may help them develop skills that will enhance their chance of success in subsequent engineering courses.

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