AC 2007-2801: A HYBRID FIRST-YEAR SCIENCE COURSE FOR ENGINEERING STUDENTS – INTEGRATING BIOLOGY WITH CHEMISTRY

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A Hybrid First Year Science Course for Engineering Students - Integrating Biology with Chemistry

Abstract

Biology is playing an increasingly important role in many engineering fields. With the typical engineering program already having a high credit hour requirement, the question becomes, how to best integrate biology concepts into a packed engineering curriculum. A typical biology course is not likely to introduce the important concepts of biology to engineering students. The solution here is to develop a hybrid course that integrates chemistry and biology.

In the course, Chemistry with Applications to Biosystems, the concept is to develop a course that integrally links important concepts of chemistry and biology. The course focuses on the areas of biology most relevant to engineers: the structure and function of biologically important molecules, and concepts of biosystems (cell proliferation, immune and nervous systems and metabolism). A special topics thread has been included to weave current events into the course. During the most recent offering the focus was on various aspects of bird flu.

This is a required course for Chemical, Civil and General Engineering students and is an elective taken by a large fraction of Mechanical Engineering students as part of the ***Multidisciplinary Engineering Foundation Spiral Curriculum***. The course is typically taken during the second semester in place of a second general chemistry course. The course has been structured to provide the background needed for subsequent study of organic chemistry and physical chemistry. The introduction to concepts of biology is also structured to provide the necessary foundation for incorporation of biological applications in upper level engineering courses such as mass transfer.

The course includes a laboratory component incorporating experiments from biology and environmental engineering concepts with classical general chemistry. Approximately one half of the experiments are common with a typical second semester general chemistry course. The remaining experiments include protein assay, enzyme kinetics, acid base behavior of amino acids and biochemical oxygen demand. The laboratory component also places a heavy emphasis on data analysis, uncertainty analysis and applications of statistics in experimentation.

This paper will detail the development and delivery of Chemistry with Applications to Biosystems. Comparative data will be presented to illustrate the performance of students in subsequent course work, particularly organic chemistry.

Introduction

Advances in science and technology during the past decade have increased the importance of the biological science in engineering. A knowledge of some significant aspects of the biological sciences is now required in many fields of engineering. To adapt to these demands, many engineering programs across the United States have struggled to determine the best way to introduce the necessary materials to their students. In this paper we discuss the path chosen at the University of New Haven (UNH). This solution involved the development of the hybrid science course Chemistry with Applications to Biosystems.

Engineering programs almost universally suffer from the issue of content overload. This problem is particularly acute when degree requirements have been capped at levels as low as 120 credit hours, generally by legislative mandate. As science and engineering evolve and new content becomes important to the engineer, universities are faced with the issue of how to integrate this knowledge. Some engineering programs have chosen to require biology courses. Others have developed upper level courses to integrate biology with engineering concepts. Still other engineering programs have been developed with the focus on the biological sciences.

Biological science concepts are important in many fields of engineering. In environmental engineering, biological systems are important in wastewater treatment and remediation of contaminated soils and ground water. In mechanical engineering these concepts are important in the design of biomechanical systems and compatibility of materials used in replacement joints, etc. In chemical engineering the list of applications are diverse, ranging from artificial organs to implantable controlled release dosing systems to the design and operation of biological based production processes such as fermenters. The course described here is designed to provide the basic level of familiarity for engineers who may become involved with any of these applications.

The Concept

After considering various approaches to incorporate biology concepts into the curriculum, the idea of the hybrid course was selected. This concept is in keeping with the overall curriculum design of the ***Multidisciplinary Engineering Foundation Spiral Curriculum (MEFSC)*** within the Tagliatela College of Engineering at UNH. Within the ***MEFSC*** a series of courses have been developed which integrate subject matter from multiple disciplines. The ***MEFSC*** supposes that engineers need a broad background of material on which to understand the world and on which to build their discipline specific knowledge. The ***MEFSC*** model calls for development of new courses using a team of faculty drawn from the represented disciplines.[1,2]

For the Chemistry with Applications to Biosystems course (EAS120) the group of disciplines represented in the development phase included chemistry, biology, and relevant engineering fields. This new course was developed to balance the requirement to incorporate relevant new content into the curriculum with the need to limit curriculum overload. This course was designed to satisfy these constraints by integrating the relevant biological science materials into an existing chemistry course. Since the new content represented about forty percent as much material as was included in the existing course, some of the existing content needed to be removed. An additional constraint was then to make sure that content needed to prepare students for follow-up courses was retained. This could be accomplished in two ways. First, much of the original chemistry content in the existing course was retained. Second, some existing content in overlap areas was modified to stress the biological science concepts. Another major advantage of this approach, combining biology with chemistry, was to highlight the importance of chemistry in the functioning of biological systems where the biological processes are controlled by the underlying chemical reactions.

The concept of integrating the materials and maintaining coverage applies to the laboratory portion of the course as well. A core set of critical experiments from the original chemistry course was retained. New experiments were developed and are continuing to be developed to illustrate the important new concepts integrated into the Chemistry with Applications to Biosystems course. The new experiments were selected in such a way that some of them illustrate the original chemistry concepts in biological systems, further reinforcing the interrelationship of chemistry and biology. In addition to the introduction of new experiments, both the new experiments and those retained from the original course were designed or redesigned to stress the development of critical laboratory skills.

The last concept to be considered in the development of this course was introducing materials that would provide the basis for better understanding of and to facilitate incorporation of biological science concepts into upper level courses in the various engineering disciplines. Some examples of this would be in the design of chemical reactors involving enzyme kinetics. This could also apply to mass transfer in biological systems and material compatibilities with biological systems for implantable devices.

Course Development

Once the general concept for the course was put into place, a development team was assembled. The course development began during the spring of 2004. The development team consisted of representatives from Chemistry, Biology, Civil and Environmental Engineering and Chemical Engineering. The development of this course occurred in parallel with the development of other integrated courses for the ***MEFSC***. Several meetings were held to consider the content of the second semester general chemistry course and to identify requirements for the new Chemistry with Applications to Biosystems course. Course materials in the original chemistry course were classified in terms of must retain, good to retain and could do without. The representative from biology introduced a list of concepts that were felt to be of most immediate interest to engineers. These included protein function, amino acids and their behavior, enzyme kinetics, and structure and function of biologically important molecules. The representative from biology suggested laboratory exercises that would be of interest and would supplement the existing materials.

This new course needed to share the same science prerequisites as the original General Chemistry II course. This new course also needed to contain the same core chemistry content contained in the General Chemistry II course since subsequent chemistry courses, such as Organic Chemistry and Physical Chemistry, would have students who had come through either route. Since this new course was being developed specifically for engineering students, the mathematical rigor could be at a higher level and the laboratory component could involve a greater emphasis on data analysis and statistical methods.

After several meetings the basic structure of the course was finalized. The main topics retained from the General Chemistry II course included kinetics, equilibrium, thermodynamics, electrochemistry, and acids/bases. Table 1 indicates the main topics that were retained, added, modified or removed in creating the new course. Additional details are provided in the section describing delivery of the lecture portion of the course. Up to this point the new course had working titles of “Lab Science for Engineers” or “Interdisciplinary Science for Engineers.”

After much discussion the course was renamed "Chemistry with Applications to Biosystems," a title that alluded to the concept of the course. The course, as was the case for other courses developed for the ***MEFSC***, did not initially have any subscribers. The various engineering programs needed to decide if this course would be required of their students. The Chemical Engineering, Civil Engineering and General Engineering faculty chose to designate Chemistry with Applications to Biosystems as a required course in their programs. The Mechanical Engineering faculty decided to recommend this course to their students to satisfy a second laboratory science requirement in their program. The Chemistry faculty has decided to allow their students to take this course as an alternative to the General Chemistry II course, a requirement in their program.

Table 1: Materials Retained, Added and Removed in Development of Chemistry with Applications to Biosystems

Topic	Disposition
Water and Solutions	retained
Equilibrium	retained
Chemical Kinetics	retained
Chemical Thermodynamics	retained
Electrochemistry	retained
Equilibrium	retained
Acids and Bases	retained
Colligative Properties	coverage reduced
Complex Ion Chemistry	coverage reduced
Solubility Equilibria	coverage reduced
Nuclear Chemistry	eliminated
Chemistry of Transition Metal Elements	eliminated
Structure and Function of Biological Molecules	added
Introduction to Biochemical Reactions	added
Biological Kinetics	added
Modern Biology	added

With the details of the course now agreed upon, the detailed development began. One of the coauthors of this paper (Dr. Schwartz) began the process by identifying a text to cover the biological science aspects of the course. The selected text was Tozeren and Byers, New Biology for Engineers and Computer Scientists.[3] This text was to be used in conjunction with Ebbing, et al., Essentials of General Chemistry, to cover the chemistry component of the course.[4] To illustrate the proportion of materials and the integration of the materials within the course, Table 2 presents a sample course schedule for the spring 2006 term. Dr. Schwartz's extensive background in chemistry coupled with her years of research with biological systems and pharmaceutical applications made her an excellent choice for developing the lectures. Two of the other authors of this paper, along with other colleagues, provided input into the initial development of the lecture portion of the course.

Parallel to the development of the lecture was the development of the laboratory portion of the course. The initial development was led by two of the authors of this paper (Dr. Koutsospyros from Civil Engineering and Dr. Harding from Chemical Engineering) in consultation with chemistry faculty. The laboratory was initially developed to leverage the existing General Chemistry II laboratory exercises that were considered most relevant. Six experiments were selected from the General Chemistry II Laboratory Manual as detailed in Saliby et al.[5] Four additional experiments were developed or adapted from other sources to incorporate biology and environmental engineering concepts for the initial offering of the course in the spring of 2005. Notes were developed and incorporated into the existing Laboratory Manual describing the underlining principles and the procedure of the experiment as well as pre- and post-experiment questions. Along with the Laboratory Manual notes, lecture notes were also developed providing a more detailed and in-depth treatment of the theoretical principles and applications of each of the new experiments. Additional details relating to specific experiments and experimental objectives are presented in the course delivery – laboratory section.

Table 2: Course Outline for Spring 2006

Review of Chemistry and Introduction to Biology
Water and Solutions
Structure and Function of Biological Molecules
Introduction to Chemical and Biochemical Reactions
Kinetics of Chemical and Biological Reactions
Equilibrium
Acids and Bases
Thermodynamics
Electrochemistry
Modern Biology

Course Delivery – Lecture

Chemistry with Applications to Biosystems was taught for the first time during the spring semester of 2005. The course consists of three hours of lecture per week (typically meets twice per week) and one three-hour laboratory session per week. There is a combined grade for this course with the lecture weighted 75% and the lab weighted 25%. The lecture meets two times per week and utilizes a "smart classroom."[i] Because of the range of experiments conducted in this course, the laboratory is currently split between two lab facilities. This paper focuses primarily on the course as taught during the spring 2006 semester.

The objectives of the lecture portion of the course are:

- To give the student insight into fundamental principles of chemistry
- To introduce integrated concepts from chemical and life sciences to engineering students
- To provide the student with engineering, environmental and biological applications of chemical principles
- To prepare students for subsequent engineering science and discipline specific courses

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[i] Smart classrooms are equipped with a computer with network and Internet access, a digital projector and a document camera

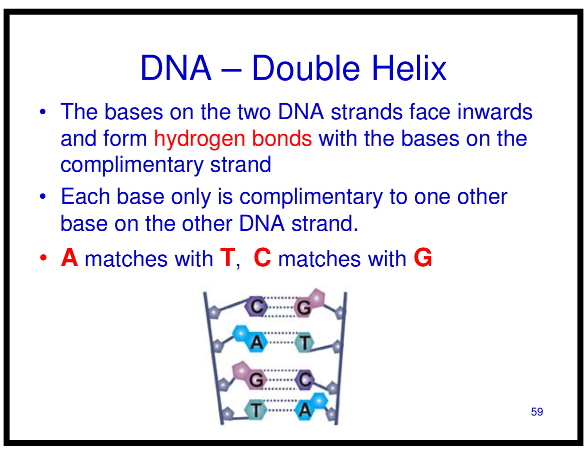
The lecture was presented using PowerPoint with many diversions to animations, internet sites and news articles. The primary assessment in the lecture consisted of three tests along with frequent quizzes that where graded in class. Course notes and other information were accessible in a Blackboard site for the course. Course notes were printed by students prior to the class and followed the PowerPoint presentations with a "fill-in-the-blank" model. For example, Figure 1 shows two slides, one given as part of the lecture itself and one as part of the student notes. This approached worked well and kept students engaged in the lecture.

The course outline was built upon the typical syllabus for second semester general chemistry. In order to allow time for more biology oriented topics, some subjects normally covered in the second semester course had to be eliminated or significantly reduced. The topics that were eliminated were nuclear chemistry and specific chemistry of representative and transition metal elements. Discussion of colligative properties and complex ion and solubility equilibria was retained at a reduced level.

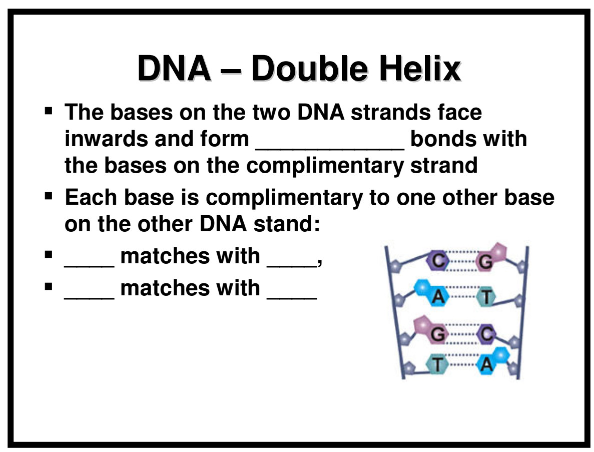
The course structure assumed that organic chemistry and covalent bonding topics were covered in the first semester general chemistry curriculum. Although these subjects are not discussed in considerable detail, it is important for students to appreciate bonding to carbon and the diversity of structures that result. These topics are essential for the Chemistry with Applications to Biosystems course and are reviewed with students at the beginning of the course.

Figure 1: Example of Instructor Lecture Slide and Corresponding Student Handout Slide

Lecture Slide



Student Handout

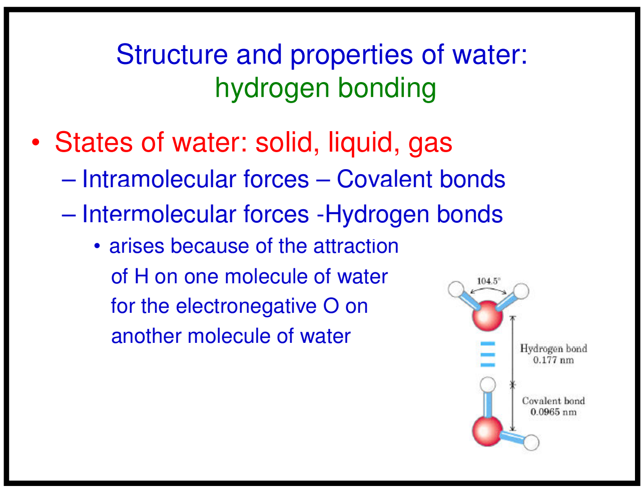


In addition to reviewing the fundamental concepts important for organic chemistry, this course begins with a review of general concepts in chemistry and biology. These include: understanding the modern theory of the atom, using the periodic table, performing calculations with moles, using formulas for compounds, understanding the Laws of Conservation of Mass and Energy, identifying common chemical reactions, balancing chemical equations, solving stoichiometry problems and appreciating basic thermochemical concepts. For biology concepts, it is assumed that many engineering students had little or no high school biology, but are familiar with the basic concepts of cells, tissues and organisms.

One element of this course that proved to be successful was the development of a current interest theme that was threaded into many of the course topics. For Spring 2006, that topic was Bird Flu and Its Treatment. At that time, bird flu was very much in the news as a possible pandemic disease. It was easy to introduce stories about the flu, especially the 1918 flu, as a prelude to describing the nature of viruses, how they interfere with normal cell function and how drugs might work against these pathogens. For example, the role of hydrogen bonding in the recognition of the virus by a mammalian cell fit well into discussions on the structure and properties of water.

The outline for the course as taught during the spring of 2006 is presented in Table 2. The first major topic is the structure of water and solutions. Water is highlighted because of is unusual chemical and physical properties that can be explained by understanding its structure; this idea that structure of a substance is fundamental to understanding the chemical and biological properties of a material is a frequent concept throughout this course. Hydrogen bonding is an important topic as is understanding of solutions, primarily aqueous solutions. Figure 2 provides an illustration of how this important concept is presented.

Figure 2: Structure of Water and Hydrogen Bonding



The first topic that focuses on the biological sciences is Structure and Function of Biological Molecules. The main components of cells are discussed to help students understand these important concepts. Protein and nucleic acids as biological polymers are discussed in detail in order for students to relate the structure of macromolecules to their function. Another important concept introduced is that many diseases can be traced to abnormal structures of biological molecules.

Chemical reactions are reviewed with a focus on understanding that chemical reactions are the result of making and breaking chemical bonds. This idea continues as biochemical reactions are described with the key concept of enzymes as catalysts of biochemical reactions. The general notion is introduced that proteins and nucleic acids are synthesized from amino acids and nucleotides. The critical concept of how information flows from DNA to RNA to proteins within the cell is described here. The role of mutations in both specific types of disease and evolution are also introduced.

Chemical kinetics is a standard topic in second semester general chemistry and it is covered fully in this course. Important concepts here are the relationships of reaction rate to concentration of reactants, catalysis and the fundamentals of reaction mechanisms. The differences between the kinetics of chemical and biochemical reactions (i.e. dependence on enzymes and changes of reaction order because of saturation) are noted along with simple kinetic characterization of enzymes. The use of enzyme inhibitors as drugs is presented along with some examples that students understand such as penicillin and AZT.

Equilibrium is a fundamental chemistry topic and along with kinetics is accompanied with a variety of calculations that often challenge students. Once students appreciate a general approach to solving these problems they are in a better position to understand the basic concepts and to apply the ideas to real problems.

Acids and Bases are covered including the connection to the equilibrium concepts for understanding weak acids, weak bases, pH and LeChatelier's principle. These basic concepts lead to understanding the behavior of buffers and related calculations. Titrations and their important as quantitative tools are related to analytical chemistry.

Thermodynamics concepts of entropy, enthalpy and Gibbs' free energy are discussed primarily in terms of chemical reactions. Important here is the understanding of the Second Law of Thermodynamics and its consequences beyond chemistry.

After reviewing concepts of oxidation and reduction, electrochemistry is described with attention to calculations related to determining electrochemical potential of chemical reactions. In addition to traditional batteries, fuel cells are discussed which is often of considerable interest to the engineering students. A key idea here is that non-spontaneous reactions can be driven to occur, which is how electrolysis takes place.

The course concludes with a review of timely topics in modern biology as related to the concepts described in this class. Genetic engineering and biosystems are noted as areas where engineers who are interested in biomedical problems could play a critical role.

Course Delivery – Laboratory

The laboratory portion of the Chemistry with Applications to Biosystems course was designed to reinforce and extend concepts introduced in lecture. Laboratory sessions begin with an introductory prelab discussion of 30 to 45 minutes. This discussion focuses on the theory behind the experiment, the experimental procedure, safety considerations relevant to the experiment and any specific instructions relating to analysis and interpretation of the experimental data. Students are always asked to assess the quality of their data, and when possible, to apply statistical methods to the assessment. To provide students with these tools, the first laboratory session of the semester is focused on data analysis, uncertainty in experiments and statistical methods. For some of the experiments, data is compiled from multiple groups and shared to increase sample size and facilitate statistical analysis.

To introduce the concepts of biology and environmental science into the laboratory, four new experiments were initially introduced when the course was developed. A fifth new experiment will be added during the spring 2007 semester. The four initial new experiments included Protein Assay by Photometric Method, Acid Base Behavior of Amino Acids, Dissolved Oxygen, and Biochemical Oxygen Demand. For spring 2007, the newly developed experiment on Enzyme Kinetics (using spectrophotemetric analysis) as well as a physiology experiment will be introduced. The new Enzyme Kinetics experiment will replace the Protein Assay by Photometric Method experiment. These new experiments balance the retention of important chemistry laboratory concepts (titrimetric analysis, rate of reaction, pH measurement) with important concepts relating to the functioning of biological systems. An attempt has been made in the delivery of the laboratory to maintain coverage of important concepts without excessive overlap as described in Table 3. Table 3 lists the experiments from the spring 2006 offering of the course. In addition to the titles of the experiments, Table 3 also lists the important concepts for each experiment.

Table 3: Experimental Objectives – Spring 2006

<table>
<tr><th>Topic/Experiment</th><th>Purpose/Skill/Knowledge</th></tr>
<tr><td>Review of Safety Procedures
Measurements in Experiments</td><td>Safety, Laboratory practices
Experimental measurements and statistics</td></tr>
<tr><td>Experiment – Dissolved Oxygen</td><td>Titration
Factors effecting oxygen solubility</td></tr>
<tr><td>Experiment – Freezing Point Depression (#)</td><td>Data analysis (freezing solution)
Colligative properties</td></tr>
<tr><td>Experiment – Rates of Reaction (#)</td><td>Initial rates
Data analysis and plotting</td></tr>
<tr><td>Experiment – Temperature and Catalysis (#)</td><td>Determining kinetic data
Comparing kinetic data – two catalysts</td></tr>
<tr><td>Experiment – Equilibrium Constant (#)</td><td>Using spectrophotometer
Developing standard curve</td></tr>
<tr><td>Experiment – Acid and Base Behavior (#)</td><td>Titration
Preparing standardized solutions</td></tr>
<tr><td>Experiment – Acid-Base Behavior of Amino Acids</td><td>Titration
Complex behavior of amino acids</td></tr>
<tr><td>Experiment – Buffers (#)</td><td>Formation of buffers
Behavior of buffers under stress</td></tr>
<tr><td>Experiment – Spectrophotometric Analysis of Proteins</td><td>Using spectrophotometer
Developing standard curve</td></tr>
<tr><td>Experiment – Biochemical Oxygen Demand (BOD) – Part 1</td><td rowspan="2">Action of microbes on organic matter
Use of dissolved oxygen to measure biochemical action
Correcting data using controls</td></tr>
<tr><td>Experiment – Biochemical Oxygen Demand (BOD) – Part 2</td></tr>
<tr><td colspan="2">(#) Indicates that this experiment is common with the basic General Chemistry II course</td></tr>
</table>

During the Spring 2007 offering of the course, a new experiment, "Investigating the Activity of an Enzyme," will be introduced. Since one of the instructors has considerable research experience with thymidine phosphorylase, it was chosen as the target enzyme for this experiment. The experimental procedure describes the general behavior of enzymes and how enzyme activity can be measured. In this case, it is possible to follow the reaction, catalyzed by the enzyme, using a spectrophotometer. The experiment has three parts: 1) determination of protein concentration of a stock solution of enzyme using a commercial protein assay kit; 2) determination of the sensitivity of the enzyme for converting substrate to product at different temperatures; 3) determination of the activity of the enzyme with different substrate concentrations at an optimal temperature. In addition to using the spectrophotometer and applying Beers' Law, students learn about the behavior of an enzyme (i.e. temperature and substrate dependence) and determine characteristics of an enzyme (i.e., V_{max} and K_m).

An example of the integration of several important course and laboratory concepts is the last experiment, Biochemical Oxygen Demand (BOD). This experiment is relatively complex for a freshman level course; however, several of the complicating factors have been addressed in earlier experiments. In the BOD experiment a sample of water from a pond or waste water treatment plant is obtained for analysis. Since the concentration of organic material is not known, the students must make an assumption of concentration, with input from the instructor, to determine the sample sizes for analysis. A microbial seed solution is added to all samples to insure sufficient biological activity. Blank solutions of seed solution and nutrient water are also prepared. The students share data and determine which samples are within the acceptable range (minimum DO or minimum change in DO) to be considered valid. Corrections are made based on change in DO of blank solutions. In addition to determining the BOD of the sample(s), the students conduct a kinetic study and determine the kinetic parameters.

This BOD experiment forces students to consider:

1) The validity of individual samples
2) The need to correct measured DO values based on activity of blank solutions
3) Determination of the value of parameters within reasonable range bounds
4) Determination of kinetic parameters.

This integration of experimental and data analysis concepts brings together similar concepts introduced individually in previous experiments.

Assessment

A preliminary assessment of performance of students who have taken Chemistry with Applications to Biosystems (EAS120) was conducted to see how they perform in subsequent course work. The most reasonable probe course for this assessment is Organic Chemistry I since this is the next course in the sequence that builds on either the traditional General Chemistry II or alternatively EAS120. At the present time it is difficult to draw significant conclusions from this data because of the small sample size. Currently the only significant group of students who take both the EAS120 course and also take Organic Chemistry I are the chemical engineering students. Since part of this group of students is not prepared to start in General Chemistry I when they enter the university, these students typically take a General Chemistry II course the summer of there first year and do not take EAS120. Coupling this with the small size of our chemical engineering program, only six students could be identified who had completed EAS120 and also Organic Chemistry I. These students are compared to two other groups to gain a preliminary picture of performance. The primary comparison group is students who take the traditional General Chemistry II and Organic Chemistry I (sample size = 19). The last comparison group is composed of students who take EAS120 but do not take Organic Chemistry I (sample size = 12). For all three groups, performance in General Chemistry I (precedes either General Chemistry I or EAS120) was also tabulated as a baseline. All of the students in this comparison who took Organic Chemistry I were enrolled in the same section of lecture.

In the assessment of student performance in the Organic Chemistry I course, the focus was to determine if students taking EAS120 were at a disadvantage relative to students who took the traditional General Chemistry II course. Performance as represented by grade received in the course was used as a measure. In the case of Organic Chemistry I, since individual grades are given for the lecture and the lab, these were combined (weighted 75% lecture and 25% lab) to put them on the same basis as EAS120. The performance of students was assessed both on the basis of individual course grades and based on a normalization of grades using the semester grade point average for the semester during which the course was taken. Table 4 presents the results on a course grade basis for the three groups.

Table 4: Performance in Organic Chemistry I - Grades

Course Grade (A=4.0)		EAS120 and Organic Chemistry I (n = 6)	General Chemistry II and Organic Chemistry I (n = 19)	EAS120 but not Organic Chemistry I (n = 12)
General Chemistry I	Mean	3.61	3.13	3.05
	Standard Deviation	0.69	0.76	0.96
General Chemistry II	Mean	-	2.68	-
	Standard Deviation	-	0.66	-
EAS120	Mean	3.38	-	3.05
	Standard Deviation	0.77	-	1.01
Organic Chemistry I	Mean	2.55	2.26	-
	Standard Deviation	1.33	0.61	-

While the small sample size of the focus group (EAS120 and Organic Chemistry I) does not allow statistically significant conclusions to be drawn, the indication is that the students in this group perform at least as well as students in the second group (General Chemistry II and Organic Chemistry I). Table 4 shows a mean grade of 2.55 (A = 4) for the focus group as compared to a mean grade of 2.26 for the primary comparison group. The very large standard deviation of 1.33 for the focus group alludes to the difficulty in drawing a strong conclusion here. The trend in the primary comparison group of the decrease in the mean grade on progressing through the three course chemistry sequence (3.13 to 2.68 to 2.26) is a likely indicator of the increasing difficulty of these courses.

To remove some of the variability in the grade data, the course grades were normalized by dividing the individual student's course grades by that student's grade point average (GPA) for the term during which they took the specific course. In this way, if a student has a difficult semester due to course load or other factors, the normalization provides a relative measure. The normalized grades in the target courses are presented in Table 5. While the normalization of grades appears to provide a better picture of relative performance, it cannot overcome the uncertainty associated with the small sample size of the focus group. There is still an indication that the students in the focus group perform at least as well as students in the second group. Table 5 shows a mean normalized grade of 0.95 for the focus group as compared to a mean normalized grade of 0.81 for the primary comparison group. The very large standard deviation observed previously for the focus group has been attenuated by the normalization. The focus group also appears to have a much smaller change in the mean normalized grade on progressing through the three course chemistry sequence as compared to the primary comparison group.

Table 5: Performance in Organic Chemistry I – Normalized Grades

Normalized Grade (Course grade/term GPA)		EAS120 and Organic Chemistry I (n = 6)	General Chemistry II and Organic Chemistry I (n = 19)	EAS120 but not Organic Chemistry I (n = 12)
General Chemistry I	Mean	1.01	0.95	0.90
	Standard Deviation	0.14	0.15	0.20
General Chemistry II	Mean	-	0.93	-
	Standard Deviation	-	0.15	-
EAS120	Mean	1.01	-	0.99
	Standard Deviation	0.11	-	0.19
Organic Chemistry I	Mean	0.95	0.81	-
	Standard Deviation	0.24	0.16	-

The performance of students in the follow-up Organic Chemistry I course will continue to be monitored in the future. As more students majoring in chemistry choose to take the Chemistry with Applications to Biosystems course there will be a larger sample population on which to draw stronger conclusions regarding performance. In order to develop a stronger assessment of the longer term learning outcomes of the course Dr. Schwartz is exploring the development of a specific instrument to assess the retention of knowledge relating to the biological science components of the course. While Organic Chemistry can be used to roughly assess the retention of chemistry concepts, there are no specific follow-up courses where biological concepts can be assessed.

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