General Chemistry for an Integrated Freshman Engineering Curriculum

David E. Nikles
Department of Chemistry, The University of Alabama
Tuscaloosa, Alabama 35487-0336, DNIKLES@UA1VM.UA.EDU

Abstract

A two semester general chemistry course sequence was developed for an integrated freshman engineering curriculum. The curriculum incorporates cooperative learning and teaming in calculus, chemistry, physics and general engineering studies courses. The paper describes the general chemistry courses, how they were integrated into the curriculum, the use of teaming, and our experience after the first two years.

Introduction

Why must engineering students take general chemistry? The universal answer is that ABET requires it. Beyond that, most engineering faculty can not give a reason, and have only a vague idea of what is taught in general chemistry. Of course the entering students have no idea why they must take chemistry, except it is required. This does not motivate them in their studies of chemistry. As a chemistry professor and instructor of general chemistry, whose livelihood depends on full sections, it is in my interest to provide valid reasons for requiring general chemistry. Engineering is about design and the execution of the designs into products that people are willing to purchase. The designs are executed in materials and therefore all engineers should have some understanding of materials. A role of general chemistry for engineering students is to provide a basis for understanding materials at an atomic level.

The College of Engineering at the University of Alabama is a member of the Foundation Coalition, sponsored by the National Science Foundation and led by Texas A&M University. One of our missions is to develop new curricula that provide entering engineering students with a basic foundation in mathematics and science and an appreciation for the engineering profession. At the University of Alabama, we have developed an integrated freshman year curriculum that incorporates teaming and cooperative learning in Calculus (MA), Chemistry (CH), Physics (PH) and General Engineering Studies (GES) courses. Here are described a two semester general chemistry course sequence, how it is integrated into the freshman year curriculum and the experience after the first two years.

The Integrated Curriculum

In our integrated freshman year engineering curriculum the students took five classes per semester for a total of sixteen credit hours. The students all attended the same 4 hour calculus, 3 hour chemistry, 4 hour physics and 2 hour general engineering studies courses. These lectures were held in the same classroom, in a three hour block from 9 am until 12 noon. The chemistry and physics laboratories met from 9:00 am until 12 noon on mornings when there were no lectures. Half the students were in the chemistry laboratory, while the other half were in the physics laboratory. There were weeks when the students attended a calculus recitation, instead of attending either the chemistry or the physics labs. On average, in a three week period, the students attended two chemistry labs, two physics labs and two calculus recitations. On two afternoons per week, the students attended the general engineering studies class, where they learned about teaming and the engineering disciplines. They did a series of engineering design projects that integrated concepts from chemistry and physics and required the use of the mathematics tools learned in calculus. The students also took a 3 hour English composition course that was not part of the integrated curriculum, but was the same course taken by all other freshmen.

Students choosing an engineering major and passing a mathematics proficiency examination were invited to join the program. The examination is given to all entering freshmen and a passing score is a prerequisite for beginning a calculus course sequence. In the 1994-1995 academic year, we ran one prototype section of 36 students, 25 men and 11 women; 12 were minority students. In the second year, academic year 1995-1996, we ran two sections with a total of 62 students, 43 men, 19 women; 10 were minority students. The scholastic performance and attitudes of the students in the FC class was compared with those of a control group. The control group was chosen from those freshmen engineering students taking the regular curriculum and having a similar profile of ACT scores and similar demographics. In table 1 is a comparison of the ACT, math placement and the ACS Toledo chemistry placement examination scores for the students entering the 1994-1995 academic year.

Table 1. Comparisons of the Foundation Coalition students and the control students.

Examination	Control	FC
ACT	28.3 ± 2.6	28.8 ± 3.5
Math Placement	48.2 ± 4.2	48.7 ± 3.2
Chemistry Placement	73%	70%

Chemistry for the Integrated Curriculum

The chemistry courses developed for the integrated curriculum were a modified two semester general chemistry sequence with the topics rearranged so as to reinforce the concepts taught in calculus, physics and general engineering studies, as much as possible. The objectives were to introduce the principles of chemistry and to provide an appreciation for the importance of chemistry to engineering. The chemistry course will prepare the students for a sophomore year materials science course and prepare the chemical engineering students for organic chemistry.

The topics normally taught in general chemistry were rearranged in an attempt to cover subject matter in chemistry that was relevant to the subject matter being covered simultaneously in physics, see Curriculum Integration, below. Another reason for rearranging the chemistry topics was to provide time for a survey of materials in the second semester. The topics covered in the general chemistry courses and the laboratory exercises are listed in Table 2, CH-131, and in Table 3, CH-132. The theme of the first semester was mass and energy balance. Beginning with the atomic theory, the students learned about chemical formula, elemental composition, elemental analysis, chemical equations and reaction stoichiometry. They then learned about thermodynamics, gas laws, kinetics and chemical equilibria. In the second semester the students learned about the electronic structure of the atom, chemical bonding and the structure of molecules. This led to an discussion of cohesive forces, both bonding and non-bonding. A discussion of phase equilibria led to a study of the condensed phases and the forces that hold together liquids and solids. In learning about crystalline solids the students were taught how to interpret powder x-ray diffraction data to determine the lattice type and unit cell dimensions for face-center cubic or body-centered cubic metals. The remainder of the course was a survey of different classes of materials, from polymers, ceramics and glasses, semiconductors, to metals. The purpose was to give the engineers a vision for the scope of materials science and the role that chemistry plays in this important field.

Curriculum Integration

Integration of subject matter across the curriculum was a major goal of our curriculum development and considerable time was spent on this goal. The calculus and physic courses found the greatest opportunity for integration, because the physics course was calculus-based. At the beginning of the first semester the physics instructors bided their time, while the calculus instructors got started. Then the calculus came just-in-time for the physics, while the physics provided real example problems for calculus. Such integration was difficult to achieve with chemistry, since general chemistry only requires mathematics at a level of high school algebra. However, we were able to find points for integration of chemistry with the calculus, physics and general engineering studies courses. The following provides examples for integration and we continue to work on improving the level of integration between the courses.

At the beginning of the first semester, the calculus instructors introduced the use of MAPLE, a symbolic mathematics program. This was done in the context of introducing the students to the concept of mathematical functions. The object was to teach the students to recognize different functional forms and to recall the equations that have that form. Chemistry and physics laboratory exercises reinforced the concept of functions by having the student acquire data having different functional forms and fit the data to empirical equations. In chemistry lab each student determined the mass of a commemorative coin and the mass of ten different six penny finishing nails. The entire class shared all the mass data and this provided the basis for constructing normal distribution curves. The students also determined the temperature dependence of solubility of different salts, which had either a linear or a polynomial form. The students found a logarithmic dependence of pH with the concentration of hydrochloric acid or sodium hydroxide. They also measured cooling curves, which had the form of a decaying exponential. Between the chemistry and the physics lab exercises, the students collected data representing most of the functional forms covered in math. The students then used MAPLE to find the empirical expressions that describe the data.

There were more points of integration between chemistry and physics. At the beginning of the first semester, the mass data collected in the chemistry lab was used as examples in physics lecture on error analysis and normal distributions. The students fit their data to Gaussian functions. The physics lab then measured one-dimensional collisions, simulated two-dimensional collisions using Interactive Physics and were introduced to the Maxwell-Boltzman velocity distribution. The chemistry lecture then used the Maxwell-Boltzman distribution to understand the kinetic molecular theory underlying the behavior of gases and the rate of chemical reactions. Another point of integration was the diffraction of light. At the beginning of the second semester the chemistry lab measured the wavelengths of light in atomic emission spectra, using a diffraction grating. The theory of light diffraction was subsequently presented in the physics lectures. The diffraction of x-rays and their use in determining crystal structures was then presented in the chemistry lectures. The optical transform kit [1] was used as a classroom demonstration of light diffraction off periodic two-dimensional arrays with different symmetry. The students were then taught how to interpret x-ray diffraction data to determine the lattice type and unit cell parameter for face-centered cubic and body-centered cubic metals.

Integration between chemistry and the general engineering studies course came in the design projects assigned in GES. The second design project was to replace gasoline in an automobile with natural gas. This required the students to learn about unit conversions. They also used the gas laws and thermochemistry from the chemistry lecture. The most satisfying integration occurred in a joint CH lab/GES design project at the end of the second semester. In the chemistry lab the students were literally asked to invent some new polyurethanes, fabricate the polymers into test pieces, and then measure their tensile properties. The engineering design project was to propose a new business development project to identify applications for the polymers invented in the chemistry lab. They prepared written proposals and made an oral report that described the invention, its application, how it would be manufactured, its cost, and how it would be marketed. The purpose was two-fold: 1) provide the students with an opportunity to make a connection between polymer structure at a molecular level and a macroscopic property and 2) provide the students with an exercise in innovation.

Teaming

In GES class the students were divided into teams of four. The teams of four attended the same lab section and they generally sat together in lecture. I did not work problems in class during lecture. Whenever the lecture required an example problem, I called on one or more of the teams to work a problem in class while I lectured. When they have worked the problem, they came to the board, stated the problem, wrote the solution on the board, explained the solution, and answered any questions. During this time they were the instructors. This got the students involved in the lecture and allowed them early experience in impromptu speaking. They discovered that it is OK to make mistakes and found that sometimes the "smart" students also don't understand. This also provided a dialog that allowed me to determine whether they understand the material.

The students worked in teams in the chemistry lab. The lab exercises were designed around the theme of data measurement, data analysis and interpretation. When the team was given the lab assignment, they decided how to divide up the work among the team members, and carried out the assignment. Each team submitted one, 3 to 5 page lab report, written in a style common to the physics and GES reports, and prepared using word processing, spreadsheet and graphing software. The team members shared the grade giving to the report. Of course, there were good teams, with cooperative team players and bad teams with uncooperative team players. There was anguish as the students learned how to work in teams. The GES class had sessions specifically aimed at developing teaming skills. There were two types of bad team players, one type would not show up for lab and not do any work. Team peer pressure, coupled with serious warnings from the faculty often corrected this behavior. Otherwise these students generally did not pass the first semester. There were times when the other team members and I wished we could "fire" those students. Another type of bad team player was the know-it-all that did everything and would not share tasks with other team members. This behavior was corrected by counselling from the faculty. A couple of times during the semester the team were switched so that the good and the bad team members were shared. By the end of the second semester, the teams functioned very well.

Assessment

In any entry level college course, no matter how high the ACT scores, there will always be a disappointing portion of the students who refuse to put in the effort required to pass the course. This curriculum demands a student work load that is much greater than the average freshman curriculum at the University of Alabama, but in my estimation an appropriate load. In the first semester of the 1994-1995 academic year about 10% of the class failed (earned a D or an F). Of that 10% one student worked hard, but could not learn the subject. The rest failed by refusing to put in the effort. The grade point average (GPA) for the chemistry class was 2.42. By the second semester, only one student earned a D, 96% passed and the GPA was 3.19. The retention rate after the first year was 72%. Similarly, in the 1995-1996 academic year, 13% failed the first semester and the GPA was 2.50. Again, the students that failed, did so because they did not put in the effort. Embarrassingly, no one earned less than a B- in the second semester and the GPA was 3.85. The retention rate for the second year's class was 68%. In both years, the students who weren't committed to working at their studies dropped out after the first semester. Some decided they didn't want to be an engineer, an acceptable outcome. The remaining students developed a work ethic that allowed them to achieve. Furthermore, the teams helped establish a network support structure. The students were clearly learning from each other and this aided the poorer students, otherwise they would have been lost.

At the end of the 1994-1995 year, the FC students and the control students were given the 1993 ACS General Chemistry Examination; control students scoring 43%, FC students 49%, and the ACS norm 54%. The FC students and the control students were given a questionnaire asking their opinion of the freshman year experience. The control students had a negative opinion of chemistry (positive opinion 11%, neutral 26%, negative 63%), while the FC students had a positive opinion (positive 61%, neutral 25%, negative 14%). Clearly, the effort to create an integrated opinion had a dramatic, positive effect on the student's view of chemistry. The data is not yet available for the second year. Work continues to find other means to assess the effectiveness of this curriculum. We will track the performance of the students as they advance through their engineering curricula.

Acknowledgments

The Foundation Coalition is supported by the National Science Foundation, Cooperative Agreement number EEC-9221460, and by the University of Alabama. This curriculum was developed and taught by the freshman teaching faculty: David W. Cordes, J. W. Harrell, Alan Hopenwasser, Jerald R. Izatt, Cecelia A. Laurie, Joey K. Parker and James A. Richardson. The chemistry graduate teaching assistants were Susan Mathew, Qiulei Ren, Halle Bagwell and Joanne Kienzle. Charles Evces, Karen Frair, Lester C. Frair and T. Wayne Merritt, all from the College of Engineering, provided insight and support.

References

1. G. C. Lisensky, T. F. Kelly, D. R. Neu and A. B. Ellis *J. Chem. Ed.* **1991**, *68*, 91-96.

Table 2. Weekly topics for CH-131, fall semester 1995.

Week	Lecture Topic	Laboratory Exercises
1	Introduction to the engineering curriculum, teaming exercises, mathematical functions	Math Recitation
2	Overview of chemistry, scientific units, classification of matter, density	General Lab: Data Collection
3	Atomic theory, chemical formulae, chemical composition, elemental analysis	General Lab: Data Collection
4	Chemical equations, reaction stoichiometry, solutions, solution stoichiometry	Density
5	Thermochemistry, energy balance, reaction calorimetry	Calorimetry
6	Gas laws, kinetic molecular theory, non-ideal behaviors	Gas Laws and Diffusion
7	Thermodynamics, first law, Hess's law, entropy	Math Recitation
8	Second law, entropy, Gibb's free energy, spontaneity	Math Recitation
9	Chemical kinetics, collision theory, rate laws, reaction orders	Kinetics
10	Activation energy, catalysis	Kinetics
11	Chemical equilibria	Math Recitation
12	Acids and bases, pH, acid-base theories	Acid-Base Titration Curves
13	Weak acids and bases, buffers	Buffers
14	Oxidation-reduction reactions	Math Recitation
15	Electrochemistry, voltaic cells, Nernst equation	Voltaic Cells
16	Electrolytic cells, batteries, fuel cells, corrosion	Math Recitation

Table 3. Weekly topics for CH-132, spring semester 1996

Week	Topic	Laboratory Exercises
1	Course overview, Materials in engineering	Atomic Emission Spectra
2	Electromagnetic radiation, quantum mechanics and the structure of atoms	Electronic Absorption Spectra
3	Electron configurations and periodic relationships among the elements	Math Recitation
4	Chemical bonding: ionic bonding and covalent bonding	Math Recitation
5	Valance bind theory and molecular orbital theory	The Shape of Molecules
6	Cohesive forces	Cohesive Forces
7	Phase changes and phase diagrams	Phase Diagrams
8	The liquid state	Math Recitation
9	Solutions and colligative properties	Colligative Properties
10	Crystalline solids, crystal lattices and x-ray diffraction	Math Recitation
11	Amorphous solids	Polymer Synthesis
12	Organic chemistry: hydrocarbons, ethers, carboxylic acids, esters, amides	Polymer Characterizations
13	Spring Break	Math Recitation
14	Polymers: synthesis, structure and properties	Polymer Characterizations
15	Ceramics and glasses	Math Recitation
16	Semiconductors and Metals	Math Recitation
17	Materials for Information Technology: Magnetic Tape and Optical Disks	Math Recitation