Abstract

For the past three years as a member of the NSF Foundation Coalition The University of Alabama has been developing an integrated freshman engineering curriculum. We describe here our experiments with integrating topics in physics and chemistry. Examples include error analysis and statistics, molecular collisions and the gas laws, wave interference and the analysis of crystal structure, and the Bohr model and the periodic table. The curriculum makes extensive use of computer tools such as Maple, Excel, and Interactive Physics, and teaming techniques are employed. We assess the merits and limitations of these attempts at integration.

Introduction

Traditionally, there has been very little integration among the subjects taken by freshman engineering students. As a consequence students often have difficulty solving problems which they can't easily classify as, for example, a 'physics' problem, a 'chemistry' problem, or a 'math' problem. Similar compartmentalization within the engineering curriculum itself often leads employers to express concern about the overspecialization of engineering graduates.

As a member of the NSF Foundation Coalition, the University of Alabama is attempting to address these and other related concerns about the undergraduate engineering curriculum. A freshman curriculum is being designed which emphasizes three thrust areas: Curriculum Integration, Technology-enabled Education, and Human Interface Development. For the past two years, the University has offered closely correlated pilot courses in freshman physics, chemistry, calculus, and engineering design. All four courses start at the beginning of the first semester and meet throughout the year in a common classroom equipped with computers, multi-media facilities and modular furniture that is designed to facilitate team activities. Common student teams function together in all four classes. Formal computer instruction is given in the mathematics and engineering design classes, and use of all of the available computer tools (Word, Excel, Maple, Netscape, Interactive Physics, etc.) is an integral part of all of the classes.

The close connection between physics and calculus is obvious, and curriculum integration is relatively straightforward. Physics and chemistry, however, are most often taught at the freshman level with essentially no effort to integrate the subject matter. This happens in spite of the fundamental similarities of the disciplines. We describe here our attempts to integrate several topics presented in these two courses. Examples include error analysis and statistics, molecular collisions and the gas laws, wave interference and the analysis of crystal structure, and the Bohr model and the periodic table.

Error Analysis, Statistics, Molecular Collisions and Gas Laws

One consequence of starting physics and calculus simultaneously is the need to devote the first few weeks of the physics course to subjects that can be treated effectively without vectors or differentiation. We view this circumstance as an opportunity for a joint chem/physics focus on statistical subjects. To begin, in both the chemistry and physics laboratories the students measure such things as the motion of a body along an air track, liquid cooling rates, and sound propagation in order to become familiar with linear, quadratic, exponential and inverse-square functions. They experiment with different ways of plotting their data, both by hand and using Excel. The mean value and standard deviation are introduced. Through individual and team exercises in which large data samples can be accumulated (e.g., weighing nails or coins) they become familiar with histograms and the concept of a normal distribution. Classroom exercises and homework assignments involving such familiar subjects as grades, speeding motorists and food packaging give them
experience using Maple to solve normal distribution and error function problems.

In the second phase, a short but general discussion of ways in which the motion of bodies can be described leads to the introduction of conservation laws as a major scientific perspective. The historical precedence of this focus on quantities that remain constant throughout the motion is illustrated with brief readings from Descartes and Leibniz. The complementary relationship between this approach and a focus on the detailed evolution of dynamic quantities is stressed throughout the physics course. While this activity is going on in the classroom, the students carry out air track and air table experiments in the laboratory which help them visualize the distinction between the two points of view and at the same time lead them to the discovery of energy and momentum conservation in elastic collisions.

Richard Feynman once said "if, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, ...(it should be) that all things are made of atoms - little particles that move around in perpetual motion, ..."[1]. In keeping with this emphasis the chemistry class pursues the study of gases as collections of atoms or molecules in motion. The statistical distribution of the molecular positions and speeds are used to obtain the ideal gas laws and the temperature dependence of chemical reaction rates. Familiarity with the Maxwell-Boltzmann speed distribution greatly facilitates discussion of the latter subject. For its part, the physics class therefore builds on the student's discovery of energy and momentum conservation in elastic collisions to set up a series of computer simulations and calculations which provide an introduction to molecular collision theory.

The students use Interactive Physics to simulate two-dimensional elastic collisions between a dozen or so particles. An example is shown in figure 1. With the initial conditions under their control, they quickly gain an intuitive appreciation of the randomness and complexity of the system's motion, and hence the need for a statistical simplification of its description. In principle, they can also determine quantitatively the mean free path and mean time between collisions from these simulations. In order to treat larger numbers of particles and collisions we turn next to one-dimensional collisions. As a team exercise the students prepare a flow chart for calculating the distribution of displacements and speeds among a set of elastic particles which start with given initial positions and speeds and then move along a straight line segment bounded by perfectly elastic walls. After a general class discussion of the proposed flow charts, they are provided with a Maple procedure which we have prepared in advance to calculate and plot a histogram of the speed distribution [2]. Individual students then choose their own initial conditions and run the program. Some typical results are shown in figure 2, which demonstrates the establishment of a well-defined equilibrium speed distribution with statistical fluctuations. For given kinetic energy, the equilibrium speed distribution is independent of the initial conditions, and the particle velocities can be reversed at any time to demonstrate that the establishment of the equilibrium distribution is irreversible. Later, the

![Figure 1. Frame from Interactive Physics simulation showing track of shaded particle.](image1)

![Figure 2. Speed distribution for 50 particles. Only one particle was initially in motion with a speed of 5 m/s.](image2)
results obtained with the one-dimensional simulation are compared to the theoretical Maxwell-Boltzmann speed distribution for a three-dimensional gas.

Chemical reactions involve the breaking of existing chemical bonds and the making of new bonds. In order for a chemical reaction to occur the reactant molecules must collide with the proper geometry and must also have sufficient kinetic energy to get over a potential barrier. The kinetic energy is used, in part, to break the existing bonds. Only a small fraction of the collisions satisfy these conditions. That fraction is given by the Maxwell-Boltzmann energy distribution, which is easily determined from the corresponding speed distribution. Increasing the temperature increases both the molecular collision frequency and the probability that a collision will have sufficient kinetic energy to drive the reaction over its activation energy barrier. These ideas are used to provide the basis for understanding the temperature dependence of chemical reaction rates. The discussion is supported by Maple exercises which employ the Maxwell-Boltzmann density and cumulative distribution functions. The student's previous experience with the normal distribution and error function is very helpful here.

Wave Interference in Optics and Crystal Structure Analysis

As part of a physics sequence on waves and optics, Maple 2d-animations, which are generated and controlled by the students, are used extensively to illustrate propagation of single pulses and harmonic waves. Subsequently, standing waves and beats are studied in the same way. Both Maple and Excel graphics are also used to illustrate Young double-slit interference, single-slit diffraction, and the transition from multiple-slit interference to single-slit diffraction as more slits are added to the interference mask. Each of these topics is further illustrated by means of laser classroom demonstrations, and two traditional three-hour physics laboratories provide hands-on experience with these phenomena. Multiple-beam interference in thin films is also treated, and Bragg diffraction by regular three-dimensional arrays is introduced in the same context.

During the same time period the diffraction of x-rays and the use of this technique to determine crystal structure is presented in the chemistry lectures. Optical diffraction is demonstrated with an optical transform kit [3]. It contains 35 mm slides having either a series of parallel lines with different spacings or a two-dimensional array of squares with different symmetries and lattice spacings. A helium-neon laser is diffracted by an array and observed on the chalkboard. Students use a tape measure to determine the diffraction angles, and then use the grating equation to determine the repeat distance of the diffracting elements. The two-dimensional arrays have either a simple square lattice or a centered square lattice. The students can observe the systematic absences of diffraction peaks from the centered lattice and understand the basis for identifying the lattice type. This is reinforced by the observation of rectangular diffraction patterns from rectangular lattices and hexagonal diffraction patterns from hexagonal lattices. The students are then taught how to interpret x-ray diffraction data to determine the lattice type and unit cell parameter for simple face-centered cubic or body-centered cubic metals. They calculate the diameter of the metal atoms and the density of the metal.

A question on the chemistry final exam required the students to identify the components in a mixture of two different metal powders by interpreting the x-ray diffraction peaks obtained from the mixture. Out of 41 students, 24 correctly identified both metals (Ni and Pb) and only 3 could not identify either metal.

Bohr Model and the Periodic Table

To support the introduction of quantum numbers into chemistry class discussions of the periodic table and valence, the physics class makes a brief excursion into atomic physics. The rationale for this departure from the otherwise entirely classical content of the physics course is that having studied planetary motion and electrostatic forces the stage has been adequately set to refine the ideas about the Bohr atom that the students bring with them from high school. All of them have, after all, previously been exposed to this subject in one way or another. By the time that the Bohr atom is treated in our course the students have also observed the discrete line spectra of hydrogen and other atoms by using a grating spectroscope in the chemistry laboratory.

In the physics class a series of Maple exercises is introduced to lead the students through the following experiences: 1) plotting circular and elliptical orbits, 2) investigating the effect of changing the angular momentum l on the ellipticity of the orbits, 3) exploring the inter-relationships between n, the orbital radius r, and the orbital energy E for circular orbits in an electrostatic field, 4) calculating and plotting orbits corresponding to discrete values of $E_n$, 5) plotting energy level diagrams and identifying the Balmer series. Wherever complicated formulas are required their general form is elucidated through team and general classroom discussions, and a
Maple procedure prepared by the instructor is then given to the students.

Whenever this type of approach was used throughout the course the students used the new Maple procedures with the same level of acceptance and facility as they do such procedures in the standard Maple library as solve, diff, plot, etc. During all such exercises questions, hints and challenges are used to promote an interactive learning environment. Some of these are contained in a written handout that accompanies each exercise, and others are evoked interactively by the instructor who roams the classroom during each exercise.

Subsequent to these exercises, the chemistry class picks up the further development of the quantum ideas required to describe atomic structure. The remaining atomic quantum numbers $m_l$ and $m_s$ are introduced by analogy to $n$ and $l$, with emphasis put on their semi-classical geometric interpretations. Atomic orbitals are described with $n$ largely defining the radius, $l$ the shape, and $m_l$ the spatial orientation of each orbital. Having previously seen the relationship between $n$ and the orbital energy for the Bohr atom, the students are now introduced to the general relationship between atomic quantum numbers and energy states. The Pauli exclusion principle is introduced, and the periodic table is built up by filling the orbitals in the sequence of increasing energy, as modified by Hund's rule. During this process the students are also shown the Schrödinger equation and introduced qualitatively to the idea that its solutions are probability functions which describe the statistical distribution of electron positions.

**Assessment**

Although we have no comparative data to assess the impact of our experiments with physics and chemistry integration, we believe that it has been an overall positive learning experience for both students and faculty. The close interaction of the faculty in planning and teaching the courses (all first-year faculty meet on a weekly basis) has resulted in standardized notation and elimination of possible duplication of material in the courses. Indirectly, physics and chemistry integration also occurs through engineering projects such as designing a natural gas storage tank for vehicles. Common formats are also required for physics and chemistry lab write-ups. Each student keeps an electronic journal in which he/she responds to specific questions that are posed to the whole class as well as recording his/her own experiences and reactions. This procedure provides invaluable feedback.

While statistical distributions and molecular collisions are natural topics for physics and chemistry integration, there was some concern about the amount of emphasis on these topics early in the first semester while students were struggling to learn basic principles of physics, coping with other new courses, learning new computer tools, and adapting to the university and Coalition environments. Although the study of atomic orbitals in chemistry follows naturally from a treatment of the Bohr atom in physics, the treatment of the Bohr model must be done at the sacrifice of more traditional topics in basic physics. On the other hand, wave optics and the analysis of crystal structure using diffraction techniques are very natural topics for integration.

The opportunities for physics-chemistry integration will diminish next year because of changes that will take place in our curriculum. Because of the very heavy workload of the students during their first semester in the Coalition and because of a perceived need to better prepare students mathematically before they begin physics, students will now begin physics during their second and third semesters in the Coalition. In addition, most of the Coalition students will only take one semester of chemistry. We will continue to study the trade-offs associated with such changes very carefully.

**References**


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