Interactive Learning in a Multidisciplinary First-Year Course

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Abstract

Recent experience with both multidisciplinary courses and course presentation based on interactive learning techniques has shown these to be effective. However, abandoning the lecture-recitation format poses special difficulties in a multidisciplinary course taught by faculty from different departments. Major potential problems include maintaining consistency in course material from section to section in multisection courses, and organizing the material so it can be presented by faculty teaching outside their area of expertise. We will present results of a one-year pilot program in which we have adopted the interactive format in the presentation of our introductory course sequence in Chemistry of Materials. We will discuss course content, student performance, student satisfaction with the course, and the faculty experience compared to the traditional course. In addition, the in-class demonstrations and team-oriented student exercises developed will be reviewed.

Introduction

Chemistry of Materials Background

In the School of Engineering at Rensselaer, all students follow a common pre-engineering curriculum for the Freshman and Sophomore years. This curriculum includes courses in the basic sciences, such as mathematics, chemistry and physics; and courses in general engineering areas such as engineering analysis, engineering design and thermodynamics. When the current curriculum was developed, roughly five years ago, a two-semester course sequence was created, namely Chemistry of Materials, that joined elements of previous courses in General Chemistry and Materials Science and Engineering into a unified, two-semester course sequence.

The two semester course emphasizes solid-state chemistry and materials properties [1]. Wherever possible, observationsof macroscopic behavior such as, for example, mechanical strength are related to microscopic level phenomena [2]. In the case of mechanical strength, the relevant microscopic phenomena would be dislocations and non-ideal crystal structures. This course is taught with faculty from two academic departments, the Chemistry Department within the School of Science, and the Materials Science and Engineering Department within the School of Engineering, working together as a team. The course currently includes two large-group lectures, and two small-group recitation sessions per week, plus a laboratory session every other week. The large lectures help ensure that all students enrolled in the course during a given semester are exposed to similar material.

Studio Physics and Mathematics at Rensselaer

Rensselaer has been a national leader in promoting interactive learning. The basic mathematics [3,4] and physics [5] courses developed at Rensselaer in recent years use teaching formats that are highly interactive. In these courses the large lectures have been abandoned in favor of studio section with approximately sixty students each. Each studio section is taught by a faculty member and a graduate teaching assistant working together. In a typical class session the faculty member will spend no more than one-half of the class time presenting new material. The students then work as teams to solve problems or to perform in-class exercises to illustrate the concepts presented just minutes earlier. The student response to these courses has been highly favorable.

These courses use computers extensively in the classroom. The use of computers a helps ensure that the material presented is consistent among the various sections. The sophisticated graphics available with the computer allow an instructor to illustrate those concepts which are hard to visualize.

Bringing the Two Together

During the 1995-1996 academic year we are running a pilot program using the studio format in a single section of Chemistry of Materials. The intent of this program is to determine whether the approach being used in Rensselaer's math and physics courses described above is valid for this course as well. A group of 40 students, selected at random are attending a section taught separately from the rest of the course. These students are not required to attend lecture. They meet for 5 hours per week, in one 1-hour and two 2-hour class sessions. In this paper we will describe the development of the course as it has occurred thus far. The impressions of the instructors as well as the student reactions to this new format will also be discussed.

Implementation of Pilot Program

Setting Up a Pilot Group

A group of students was randomly selected by the Registrar and assigned to this course. These students were divided into teams of four students each during the first week of class. To assist us in setting up these teams, and encouraging teamwork within the class we made use of services available in the Archer Center for Student Leadership Development. This center was established five years ago to offer students at all levels many opportunities to enhance their leadership skills through a variety of interactive learning experiences [6]. On the first day of class staff members from the Archer Center discussed the importance of working as a team. The students were then given a survey which asked them to describe their work habits. Based on this survey the Archer Center Staff assigned each student to a team prior to the second class session. During this class session the students were given a team building exercise, which required them to work together. Given a picture of a "TinkerToy" structure, the teams had to assemble the structure, and devise a plan that would allow them to do it blindfolded [7]. In addition to serving as a team building exercise, it also "broke the ice" so that the students would more readily work together on class exercises.

Syllabus and Grading Plan

We used the same syllabus and grading criteria as were used in the traditional section of the course. Both instructors have had several years experience teaching Chemistry of Materials. We first expose the students to a basic set of rules and observations, for example that a system tends toward its lowest energy state, or Planck's observation that the energy of a light wave is proportional to its frequency. We gradually increase the scale of our observations from the sub-atomic level to the scale of engineering materials. As described earlier, in this course we explain macroscopic observations in terms of microscopic phenomena. In the first semester we look at sub-atomic particles and use the characteristics and interaction of these particles to explain the properties of atoms. We then examine the interactions of atoms to explain the properties of molecules. As the course progresses, we use the properties of molecules to explain the characteristics of materials, and then materials systems. The first semester syllabus was as follows:

Course Syllabus

Review of Basic Math, Physics and Chemistry.
Atomic Structure - Sub Atomic Particles, Nuclear Reactions, Basic Quantum Physics, Electron Configuration.
Periodic Table of the Elements

Bonding -	Lewis Structures, Ionic, Covalent, and Metallic Bonding, Hybridization, Molecular Geometry, Non-octet Compounds. Intermolecular Forces.
Gases -	Ideal Gas Law, Kinetic Theory of Gases.
Equilibrium-	Equilibrium Constants, Lechatelier's Principle, Acids and Bases, Buffers.
Thermodynamics -	Heat, Work and Energy, Calorimetry, Determining Enthalpy Changes, Entropy and the Second Law, Gibbs Free Energy, Equilibrium Constants, Vapor Pressure.
Kinetics -	Reaction Rates, Orders of Reactions, Rate Constants, Reaction Mechanisms.
Crystallography-	Basic Cubic Crystal Systems, Points, Planes and Directions, Density Calculations, X-ray Diffraction.
Crystal Structure-	Complex Crystal Systems, Ionic Compounds
Crystal Defects-	Point Defects in Metals and Ceramics, Dislocations, Surfaces, Grain Boundaries.
Diffusion-	Flux, Fick's First Law, Random Walk Model
Phase Diagrams-	Equilibria, One Component Diagrams, Phase Rule, Two Component Systems
Kinetics in Solids-	Nucleation and Growth, Precipitation Hardening, TTT Diagrams
Mechanical Behavior-	Stress, Strain, Elastic Behavior, Plastic Deformation, Hardness, Failure, Fatigue, Creep
Organic Chem.-	Functional Groups, Reactions
Polymers-	Polymer Reactions, Glass Forming Behavior, Mechanical Properties of Polymers
Electrical Props.-	Conductivity, Resistivity, Band Theory of Metals
Electrochemistry-	Free Energy Relationship, Standard Potentials
Semiconductors-	Intrinsic, Extrinsic, Devices
Materials Selection	Case Studies

Our Grading Rationale was also consistent with the larger section of the course;

Homework and Class Participation (15%)
Lab Material (10%)
Quizzes (15%)
Class Examinations (40%)
Final Examination (25%)

Note that any material used in determining the course grade was based on a student's individual effort. The in-class team exercises were designed to help the students master the material before attempting it on their own.

Class Format

The typical class period was approximately two hours in duration. During this time the instructor would present class material, and answer questions as they arose. Following the presentation of material, the class was given a problem, or set of problems, to solve. These problems were designed so that they would take between fifteen and twenty-five minutes to solve. As the class was solving the problem the instructor and the teaching assistant would walk around the classroom to provide assistance where needed. The description above describes the typical class session. However, on occasion this format was varied slightly.

<u>Lecture / Problems/ Discussion</u>

Usually we were able to complete two cycles of lecture/problem solving/discussion in a single two hour class period. That is, the instructor would present new material, the class as teams would solve problems, and we would discuss these problems as a group. Frequently this discussion was used to lead into the next concept. For example, when discussing the Ideal Gas Law, the students were asked to determine how the pressure of a container of nitrogen would change if the volume, number of moles of nitrogen, and temperature were changed. During the discussion the students were asked “How would your answer change if oxygen were added to the container instead of nitrogen?” This led into the presentation of the Kinetic Theory of Gases.

<u>Demonstrations Integrated Into Class</u>

When possible, demonstrations were incorporated into the presentation of material. Typically the students were then asked to analyze the experimental data. In this manner we were able to illustrate concepts in front of the students, as well as teach and discuss experimental techniques. The concept of experimental error is difficult for most freshmen to grasp. By analyzing real data, with the assistance of an instructor, one is able to illustrate experimental error.

Demonstrations and Experiments

As mentioned above, an integral portion of the interactive approach is the presentation of hands-on experiences both in the classroom and in an accompanying laboratory. A summary of the demonstrations and laboratories developed for this course is given below:

First Semester

1. Conservation of Energy

A putty ball was raised above a table top, then released. It was explained that as the ball fell, the initial potential energy of the ball was being converted to kinetic energy. The students were then asked to account for what happened to the kinetic energy when the ball struck the table. Responses included heating of the ball and table top, deformation of the ball, and the generation of an acoustic wave.

2 Graphing of Data

Current vs. voltage data were generated for a resistor and a diode. The students were asked to plot the two sets of data so as to generate linear plots. This gave them experience at working with non-linear functions, and at manipulating data to fit a formula.

3. Photoelectric Effect

A system was put together that consisted of a vacuum photodiode in an enclosure and a system for biasing the diode to suppress photoemitted electrons. The photocurrent was first measured with the diode illuminated with red laser light, and the bias required to suppress the emission measured. Students then calculated the work function of the cathode of the diode using the wavelength of the laser light and the suppressor bias. The diode was then illuminated with light from a green laser, and the bias increased until the photocurrent was again cut off. The students then calculated the wavelength of the light from the green laser, using the cutoff bias and the previously calculated work function.

4. Covalent Bonding

We used the program "Hyperchem" to show the charge distribution in the bonding orbitals on a variety of molecules having pure or polar covalent bonds. The students could see the effect of increasing electronegativity difference between the two atoms of a bond and the asymmetry of the charge distribution. (For example, comparing H_2 to HCl.)

5. Graham's Effusion Law

A system was put together consisting of a small chamber, fitted with a pressure gauge, connected to a vacuum pump through a small orifice. Students measured the rate of effusion of different gasses by plotting pressure vs. time for the various gases, then determining the molecular weight of an unknown gas using Graham's law.

6. Equilibrium Vapor Pressure

A system was put together with a small chamber, equipped with a pressure gauge and a reservoir that was filled with benzene. The chamber was then pumped down, with the benzene frozen out, and the sealed. Students measured the pressure in the system at temperatures between 0C and room temperature, and plotted the data to determine the heat of vaporization.

7. Heats of Reaction and Calorimetry

An instant "cold pack" was activated and passed around to show temperature changes on solution. Students were asked to think about why a process that absorbed energy was spontaneous, as a lead in to the subject of entropy, which was discussed in the next session. A simple calorimeter made from a dewar flask, water, a stirring bar and a thermometer and used to determine the heat evolved during the dissolution of calcium chloride. Students used the temperature rise in the calorimeter, along with heat capacity data, to determine the molar heat of solution of the calcium chloride, and discussed the sources of error in the measurement.

8. Entropy

Students used a model of a crystal with vacant sites to develop the concept of entropy in terms of the number of possible configurations of a system having essentially the same energy, and the concept that entropy approaches zero as the number of configurations approaches unity.

9. Crystallography

Computer animations developed in house were used to show the structure of various cubic unit cells. The animations can show both stick model and space-filling unit cells, can construct the unit cell one atom at a time, can show the various planes within the cell, and can rotate the finished cell.

Second Semester

1. X-ray Diffraction

The two-dimensional unit cell optical transforms developed in the Department of Chemistry at U. W. Madison were used along with a low power laser to demonstrate the effect of crystal symmetry on the diffraction pattern of a crystal and the application of Bragg's law.

2. Dislocations

Plastic foam models have been developed to show the process of creating dislocations by partly cutting a solid and shearing it to show how the atomic planes are aligned in the vicinity of the dislocation, and to show the shear offset associated with passage of the dislocation through the material.

3. Solid State Diffusion

A computer simulation prepared as part of the Visualizations in Materials Science from North Carolina State University [8] was used to show graphically the course of solid state diffusion by a vacancy mechanism.

4. Phase Equilibria

Students measured the Sn-Bi phase diagram by measuring the cooling curves for a series of molten Sn-Bi alloys. Each team took data for one composition, then the results were then pooled so that each team could construct the phase diagram.

5. Heat Treatment

The precipitation hardening of aluminum alloys was studied in a solution anneal, quench, and precipitation anneal sequence, with the hardness measured using a commercial hardness tester. The process was explained in terms of the Al-Cu phase diagram and the processes of precipitate formation in a diffusion- controlled reaction, followed by overaging and loss of coherence.

6. Fatigue

The process of fatigue failure was demonstrated by showing that a wire too strong to be pulled apart by hand can be broken easily by repeated bending.

7. Corrosion Fatigue of Glass

Thin glass rods were damaged by scratching with a file, then loaded in a cantilever configuration close to the breaking point. Moistening the scratched area resulted in immediate failure.

8. Electrochemistry

A commercially available simulation was used to demonstrate the operation of an electrochemical cell.

9. Semiconductors

Students fabricated a diffused junction diode, using a small piece of n-doped silicon wafer and a small piece of indium shot. Melting the indium on the silicon, then allowing it to solidify produced a p-n junction at the interface. Addition of electrical leads permited measurement of the diode characteristic. The experiment shows the role of phase equilibrium in the doping process, as well as the factors important in diode performance.

As time permits, additional demonstrations or experiments will be added to the above list. In this pilot program most of the experiences described above were done by the instructors as demonstrations, due to the limited number of setups available (usually one). Further development of some of the current demonstrations is also planned, with the eventual goal of making all of them direct hands-on experiments for the students.

Discussion

In this section we will discuss the results of our experience while developing and teaching this interactive version of Chemistry of Materials as well as some potential plans for the future.

The Teams

Well-functioning teams are required if the student is to have a successful experience in this course. Carefully and quickly setting up a team is important, as is encouraging the team to work together throughout the semester.

Value of Team Building Exercise

By and large, the teams seemed to work well together. We feel that the leadership survey has some merit. The team building exercise did cause many teams to break the ice. In this project they were required to work together. Students who may have been shy, or reluctant to work with others, seemed to become willing to work with others. While the team-building exercise was successful, the students need to be challenged immediately. We did this by introducing challenging problems where the correct solution may not have been immediately apparent early in the course.

Team Dynamics

While many teams worked well together, there were some problems. In some cases the students worked these out on their own. One student on a weak team proceeded to move to work with a neighboring team and eventually changed teams. In another case, after some prodding by the instructors, a weak student who had been teamed with three stronger students, began to participate in team problem solving and improved his performance in the course. The main problems were caused by students who simply did not attend class. However it must be noted that class attendance was far higher than in the conventional recitation sections of the course.

When the students sit together in groups of four there is undoubtedly some chatter that will occur as the instructor is talking. On several occasions the teaching assistant approached such a group and discovered they were talking about the material the instructor was presenting. They were asking questions among themselves to clarify points being made, before asking the instructor.

Various Formats

As stated earlier, most classes were structured so that the students solved problems as a team following the instructor's presentation of material. Early in the semester we realized that we had to have the students check their answers before they left. Shortly thereafter we modified the instructions so that the entire team had to have the problem solved correctly, and each member of the team had to be able to explain the solution to the instructor or the teaching assistant. This has been successful.

Problems Integrated into Class

Integrating problems into the class has worked well. The students' performance on homework assignments indicates that they are understanding the material better. The homework is graded on an effort basis and the students were encouraged to ask questions by writing on the homework paper if they were confused. They tended to do so, which allowed the teaching assistant to clarify the material. Wherever possible, quizzes from a previous year were used for the weekly quiz. This allowed comparison of student performance between the two years. Overall the quiz average improved in the interactive format.

When integrating problems into the class, one has to be cognizant of two factors, the background material needed to solve the problems, and the time required to solve the problem. By working with the students more closely a rapport builds between the students and the instructors. The students ask many more questions than in a traditional recitation. While the instructor answers these questions, he must constantly be aware of the time remaining. This is especially true during sessions in which a homework assignment is collected, a homework assignment is due, or a quiz is given. Sometimes it proved necessary to withhold a problem, that had been planned for that session. This was often accompanied by the instructor deviating from his planned presentation to further clarify a point that the students were having trouble with.

Demonstrations

The demonstrations were well received by the students. However they require careful preparation and rehearsal. In many cases we took the data for the students and had them analyze it. With the exception of the computer demonstrations, there was usually only one apparatus. When performing the experiment, we took advantage of the opportunity to show the students how to carefully perform an experiment.

Better Student Faculty Interaction

There was an increased amount of student-faculty interaction in this pilot section. The students were more likely to contact the instructor by e-mail or make appointments for extra help. The instructor found it easier to keep track of students. Typically this problem was first identified by a poorly functioning team. It is possible to keep track of each team's performance, when there are only ten to twelve teams. This enabled us to quickly identify problems within a team, usually seeing that there was a student who was having an inordinate amount of difficulty. In this manner we were able to identify students who were having trouble with the course. In one case the problem was solved by helping a weaker student work with the three stronger members on the team. Many times it involved encouraging students to speak out, ask questions, and work with their teams. We believe that there were at least 4 out of 40 students who avoided failure because we could identify that they were having trouble. By dealing with the problem in class, we helped several students who might have slipped through the cracks.

Conclusions

Indications are that the studio format produced results, in terms of exam scores, that are at least as good as the course as a whole. We feel that this format has allowed us to identify students with problems earlier than would be the case in traditional recitation sections, and to give them help as necessary.

With a few exceptions, the students enjoyed the format. We had only one student drop out between semesters and attracted two new students from the traditional course. Class attendance has been significantly higher for the pilot section than for conventional recitation sections.

Over the course of the year, we have refined our presentation techniques as we have developed a better appreciation of the time that the students will require to solve a given problem, and have learned a lot about the way in which leading questions can be used to help students past sticky points in problem solving.

Student evaluations at the end of the first semester were uniformly positive. The team problem sessions received an especially positive rating. The course will be evaluated again at the end of the academic year using comparative exam scores and surveys of student satisfaction with both the pilot program and the main course. If the results of these evaluations are favorable to the studio format, transitioning the whole course to this format was accomplished over a three to four year period.

An appraisal was made of the personnel required to implement the studio format for the course as a whole relative to current personnel requirements. This appraisal indicated no significant difference in the overall impact of faculty and teaching assistant time.

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Biographical Information

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