Session 2253

A Laboratory-Driven General Chemistry Course for Engineering and Physical Science Majors

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Abstract

A laboratory-driven General Chemistry course for engineering and physical science majors has been implemented at the University of New Hampshire. The centerpiece of this effort is the development of Chemprojects. Chemprojects are three-week long projects in which student teams investigate chemically-related problems from various disciplines, including chemistry, engineering, materials science, biochemistry, earth science, soil science, and environmental science. Chemprojects are developed in consultation with faculty from these disciplines and industry. Science education experts are evaluating the effects Chemprojects on student practices, attitudes, and performance. This paper discusses various aspects of the Chemprojects curriculum reform, including: objectives, description of implemented Chemprojects, modifications to lecture and laboratory format, student teams, description of evaluation methods, and preliminary student reactions.

The General Chemistry Curriculum: What Is Needed?

There is an increasing amount of chemistry involved in numerous recent research and technology developments. Many of these developments involve interdisciplinary teams of scientists and engineers working synergistically. For example, the manufacturing of integrated circuits in the semiconductor industry is a series of chemical deposition and etching reactions.[1] Biosensors rely on immobilized proteins as part of the sensing mechanism that detects the protein's substrate. These proteins are immobilized on synthetic lipid membranes.[2] Mechanical and electronic devices are being designed at the molecular level. These miniature microelectromechanical systems are known as MEMS and they are manufactured using semiconductor device fabrication. The acceleration sensor used to activate automotive air bags is a MEMS device.[3] Individual molecules can be mechanically positioned at room temperature.[4] Computational studies are being performed on the dynamics of molecular-sized gears consisting of shafts made from carbon nanotubes and gear teeth that are benzyne molecules bonded to the nanotube. [5]

A General Chemistry curriculum that is representative of these state-of-the-art developments must address the growing relationship between chemistry and other disciplines, such as engineering, materials science, and biology. General Chemistry should make students aware that current technological problems require interactions among engineers, chemists, and physicists. Furthermore, from a pedagogical perspective, it is optimal if General Chemistry provides students with an experience in which they are enabled to function similarly to practicing teams of scientists and engineers. Simply put, we want to produce students who have had practice working in interdisciplinary teams and solving interesting problems related to chemistry and their chosen discipline.

One way to accomplish these goals is by a re-invented laboratory driven General Chemistry course. Such a course would have the following attributes: broad appeal across the disciplines, open-ended projects requiring students to apply General Chemistry concepts in order to solve the problem, collaborative exercises with peers and instructors, and interactions with industrial scientists. This approach accomplishes objectives important for any curriculum related to introductory science and engineering majors. First, students see how chemistry is important to their future vocation as an engineer or scientist. Students capture some of the excitement and frustration encountered by practicing scientists and engineers. Students actively practice higher-order thinking skills because they must apply concepts learned in the classroom to solve problems in the laboratory. Finally, students learn in a setting that has been constructed to be representative of the working practices of scientists and engineers.

A laboratory-driven project-based General Chemistry course for engineering and science majors is being developed and implemented at the University of New Hampshire. This curriculum reform effort has been an on-going collaboration between the Departments of Chemistry and Education for the past four years. Science education experts in the Education Department are evaluating the effects of the curriculum reform.

The centerpiece of these efforts is the development of Chemprojects, which are the laboratory experiences developed for this course. Chemprojects are three-week long projects in which student teams investigate current problems from various disciplines, including chemistry, engineering, materials science, biochemistry, earth science, soil science, and environmental science. One of the unique aspects of Chemprojects is that they are developed in consultation with faculty from these disciplines and industry. The interdisciplinary nature of the project topics brings a motivating state-of-the-art focus to General Chemistry and illustrates the importance of general chemistry principles to other science and engineering disciplines.

The General Chemistry Curriculum: What Exists Now?

Traditional college chemistry instruction has had difficulty engaging the scientific excitement of students for several reasons.[6-9] First, the traditional laboratory has been a place where theory is verified rather than where questions are generated and investigated.[10-15] A recent survey of General Chemistry Laboratories in the United States from 203 institutions indicated that ninety-one percent of the respondents said that students almost always follow step-by-step instructions from a laboratory guide.[16] A second issue is curricular isolationism. Chemistry curricula have not provided students opportunities to experience the interdisciplinary and collaborative thinking that has supported recent research advances in science and technology.[17-19] Although current reform efforts present applications of chemistry in environmental, industrial, or biological settings, young college students don't have the chance to see scientists (including their instructors) thinking about chemistry as they solve problems in their disciplines. Thirdly, traditional faculty beliefs about teaching and learning must be challenged in order for them to consider how to move students to value higher order thinking and professional collaboration.[20-21] This situation exists in part from simple lack of awareness of advances in cognitive science and educational theory[6, 22-26], lack of confidence or encouragement in trying new pedagogies[27-29], and the sheer logistical hurdles involved in reforming a General Chemistry course that often has hundreds of enrolled students.

The idea of a laboratory-driven curriculum is not new. In the FIPSE (Department of Education Fund for the Improvement of Post-secondary Education) Lectures on Chemical Education delivered at the 10th Biennial Conference on Chemical Education in 1988, John W. Moore advocated a laboratory-centered curriculum, as well as student active learning, a flexible curriculum, and a course better integrated with other disciplines.[30] Although project-based laboratory instruction tends to be an integral part of many engineering programs, it has been used less systematically in chemistry, particularly in General Chemistry. A literature search of *Chemical Abstracts* uncovered many descriptions of "project laboratories" concerning isolated topics, but individual work rather than collaboration was the norm and interdisciplinary focus was lacking. More activity along this line is also evident in recent NSF proposal awards.[31-34]

Objectives of the Chemprojects Curriculum

The Chemprojects curriculum has technical and pedagogical objectives. It has an interdisciplinary content that relates General Chemistry principles to other fields because the projects are developed from topics related to the disciplines representing the career goals of the students in the course. Particular emphasis is placed on students working collaboratively on open-ended investigations which do not have predetermined procedures or outcomes. Thus a premium is placed on development of decision-making ability and understanding of chemical concepts necessary to solve a problem. Faculty from the chemistry and engineering departments have assisted in designing these projects and have been guest lecturers in the course. These faculty will be drawn into a reflective discourse about the teaching and learning practices in the Chemprojects curriculum.

A key goal is for the Chemprojects curriculum to become a vehicle for changing the norms of teaching and learning for students and faculty of General Chemistry. Current norms channel the student into the role of passive receiver of information, competing with classmates, learning that doing science means following procedures correctly, and studying chemical phenomena disembodied from technological applications.[5,17,35-36] Current norms also channel a faculty instructor into the role of information transmitter and teaching in isolation from faculty in other disciplines.[17,35] New norms, to be established and nurtured by this new curriculum, are collaboration, communication, and reflective practice among students and faculty. Chemprojects and their surrounding course context are described in the following sections.

Context of Our General Chemistry Course Before Chemprojects

Prior to the implementation of the Chemprojects curriculum at the University of New Hampshire, students used to work in pairs in the laboratory. They followed the procedures in "cookbook" style experiments, filled in data sheets, and performed rote-type calculations in the laboratory. Pre- and post-laboratory exercises consisted of answering questions related to procedural issues or repetitive calculations. The experiments often were disconnected from the lecture syllabus. The laboratory portion of the course was worth 20 to 25% of the total course grade.

During the past three years, the Chemprojects curriculum has been implemented in an advanced level one semester General Chemistry course for engineering and science majors in the College of Engineering and Physical Science. The student population for this one semester course (CHEM 405) consists of first-year students in chemistry, physics, biochemistry, and all engineering disciplines. They have all taken at least one year of high school chemistry and have reasonably strong mathematics skills in algebra, exponential notation, and real number calculations. Over a number of years the proportion of female students has been 30 to 35%. The course is offered in both fall and spring semesters. In the fall, approximately 125 are enrolled; in the spring, about 50. Enough lab sections are run, each supervised by a graduate teaching assistant, to maintain a population of less than twenty-five students per section. The laboratory meets one afternoon weekly for four hours. The lecture portion of the course meets for three fifty-minute periods weekly.

Description of Implemented Chemprojects

Chemprojects are three week long open-ended investigations related to chemistry and engineering. Prior to the week a Chemproject begins, student teams are issued a package which contains the project objectives, detailed procedures they need to follow, and a set of references, such as *Scientific American* articles or web-site descriptions pertinent to the project. Teams are expected to meet outside of lab to develop a project plan.

Students work in teams of four to design and implement experimental plans that answer the questions posed by Chemprojects. Typically, there is time to only run three Chemprojects in a semester. Five Chemprojects that have been implemented in our General Chemistry course (not all in one semester) are described below. Chemprojects are structured so that the students must understand the principles covered in lecture in order to accomplish the project. An underlying premise of this approach is that creating this "need to know" will enhance student motivation for understanding General Chemistry principles.

- <u>The Synthesis, Characterization, and Scale-up of a Pharmaceutical Product.</u>

  Student teams choose to synthesize aspirin, acetaminophen (active ingredient in Tylenol), or benzocaine from established micro-scale synthetic procedures. The students are provided synthetic procedures only; they are not given amounts of reactants to mix together. They are expected to calculate reactant quantities using their knowledge of stoichiometry from the lecture portion of the course. They characterize their compounds by melting point, gas chromatography-mass spectrometry (GC-MS), and elemental analysis. The open-ended part of the project involves determining how the yield of the reaction changes as they scale up the amount of product from 0.3 to 10 g. Student teams are required to attempt six to ten different reaction scales in duplicate. Alternatively, students may determine the variation in the yield of the reaction as a function of reaction conditions.

This Chemproject is run at the beginning of the semester because it relates to topics covered at the beginning of General Chemistry, including: compounds, physical and chemical properties, chemical formulae and reactions, mass spectrometry, separation techniques, elemental analysis and determination of chemical formulae, stoichiometry, limiting reagent, and percent yield. Students are generally excited about making a pharmaceutical product with which they are familiar. They are particularly interested in the analysis of their product with a state-of-the-art instrument, namely the GC-MS, which is part of the General Chemistry laboratory. Additionally, each team is required to submit one of their samples to the University Elemental Analysis Laboratory. Students use this data to determine the empirical formula of the substance they have made and whether it is the targeted compound. This process adds significance to the empirical formula calculations discussed in lecture because the students need to know the material in order to accomplish their project goals. Finally, this project provides the context for a discussion of the various roles of chemists and engineers in the manufacturing of pharmaceutical products.

- <u>The Enthalpy of Combustion of Oxygenated Fuel Mixtures</u>

Using home-made calorimeters, students determine the heat of combustion of various mixtures of octane with an oxygenate of their choice from among ethanol, propanol, isopropanol, and ether. They measure six to ten mixtures in duplicate, ranging from 0 to 100% oxygenate. Additionally, the students design a modification to their apparatus in order to determine the soot production by the combustion of their fuel mixtures. The students compare their mixtures to pure octane in terms of enthalpy of combustion per gram, soot production, and cost per gram. Theoretical calculations for the enthalpy of combustion are compared to the measured values.

This Chemproject is run during the coverage of thermochemistry in the lecture. The relevant topics include: calorimetry, calculating heats of reaction using heats of formation, calculating heats of reaction using bond breaking and bond making, and combustion. The relevant interdisciplinary topics that can be discussed in the context of this project include: petroleum-based and coal-based fuels, renewable energy sources, hydrogen as a fuel, the enzymatic production of hydrogen, carbon nanotubes as a means to store hydrogen, and pollution aspects resulting from the use of these fuels.

- <u>The Synthesis of Rubber-Toughened Copolymers</u>

  Students use a water-based emulsion polymerization to make copolymers with varying ratios of polymethylmethacrylate (PMMA) and polybutylacrylate (PBA). PMMA is a stiff rigid material and PBA has a glue-like consistency. Students qualitatively assess the mechanical properties of the copolymer as a function of its composition.

  This project is best run during or after the coverage of intermolecular and intramolecular bonding. It is particularly useful at demonstrating how intermolecular forces influence the structure and properties of substances. Structure-function relationships are useful for explaining the importance of bonding to students. Other relevant topics that can be discussed during this Chemproject include polymers, materials science, and mechanical properties of materials. This last topic is particularly interesting to mechanical engineering students who find it difficult too see the relevance of chemistry to their profession.

- <u>The Effect of Phospates on the Cleansing Ability of Detergents</u>

  Students design and implement a quantitative procedure that determines the effect of added phosphate on the cleansing ability of a detergent. A solution of beta-carrotene is provided to the students as a stain source. This project uses visible spectrophotometry as an analytical technique. The students learn about Beer's law and spectroscopy during the portion of the course that introduces the electromagnetic spectrum and the concept of quantitized energy levels in atoms and molecules.

  This project can be run during coverage of two topics in the General Chemistry curriculum, either light and spectroscopy or bonding. If it is run during the discussion of light and spectroscopy, then the focus of the project is the importance of spectroscopy as an analytical technique in various applications, such as environmental science. Alternatively, the focus of the project can be the various types of bonding involved in detergent action. A variation of this project involves determining how the alkyl group chain length on the detergent affects its cleansing ability.

- <u>The Synthesis and Use of a Chemical Vapor Deposition Precursor to Copper</u>

  Chemical vapor deposition (CVD) is an industrially important technique for making thin films, especially in the manufacturing of semiconductor devices. There is significant technological interest in making copper films for metallization in these devices. Students will use a water-based inorganic synthesis to make a copper CVD precursor, namely copper(II) acetylacetonate. They construct a simple CVD reactor using a small tube furnace, tubing, and flow meters. The open-ended part of the project involves them visually characterizing the variations in the deposited films as they change reaction conditions or process variables, including temperature and gas flow rate.

  The CVD project relates well to the topic of ideal gases. Students have to understand the ideal gas law calculation in order to calculate gas flow rates under various conditions.

CVD is also a technologically important example of gas-phase reactions. Finally, semiconductor manufacturing is a good example of the synergism among chemists and engineers.

Other Aspects of Course Structure in the Chemprojects Curriculum

Lecture and Laboratory Syllabi

Table 1 shows the lecture and laboratory syllabi during implementation of the Chemprojects curriculum. Two traditional laboratories were run for assessment purposes during the first year. The sequence of Chemprojects is carefully selected to provide maximum overlap of topic relevance between the laboratory and the lecture.

Table 1. Chemprojects Curriculum Lecture and Laboratory Syllabi

Week	Laboratory	Lecture
1	Orientation, pre-test	Formulas, stoichiometry
2	MgO traditional lab, Pharmaceutical	Formulas, stoichiometry
	Chemproject distributed	Mass Spectrometry
3	Project plans due, Chemproject 1	Ideal Gas Law
4	Preliminary reports due, Chemproject 1	Kinetic Theory of Gases
5	Preliminary reports due, finish Chemproject 1	Thermochemistry
6	Traditonal Enthalpy Lab	Thermochemistry
7	Project plan for Enthlapy Chemproject 2	Thermochemistry
8	Preliminary reports due, Enthlapy Chemproject 2	Atomic Structure
9	Preliminary reports due, finish Chemproject 2	Atomic Structure
10	Oral presentation s of Chemproject 2	Periodic Properties
11	Project plans due, Polymer Chemproject 3	Lewis Structures, Polarity
12	Preliminary reports due, Polymer Chemproject 3	Intramolecular Bonding
13	Preliminary reports due, finish Chemproject 3	Intramolecular Bonding
14	Post-test, lab check-out	Intermolecular Bonding

Sometimes a constant direct connection between lecture and laboratory is impossible. For example, the ideal gas law and kinetic theory of gases is covered in lecture between the Pharmaceuticals and Enthalpy Chemprojects. This discontinuity between laboratory and lecture has been minimized by various curriculum modifications. Post-project discussion sessions have been introduced into the laboratory during weeks between projects at the request of students. These sessions, led by the teaching assistants, help students to graphically analyze their project findings, compare findings among teams, and understand how the project relates to the topics in the lecture part of the course. These sessions also allow the lecture to "catch-up" to the laboratory.

When a Chemproject begins in the laboratory before the relevant topics have been covered in lecture, we have found it useful for the professor to give a short fifteen to twenty minute introduction to the project during lecture. This interlude lecture is designed to set the stage for upcoming topics. This approach has always been used to introduce the Polymers Chemproject, which starts long before all the lectures related to inter- and intra-molecular forces are completed. This interlude lecture usually occurs after the coverage of electron configurations. The lecture explains how atomic electronic configurations influence bonding. The bonding in substances affects their structure, which in turn affects their properties. The topic of polymers and their various properties is then introduced to the students. It is explained that bonding affects the structure and properties of polymers. Understanding this bonding enables scientists to tailor polymers with specific properties. Thus a connection is made between the theory-based topic of bonding and the application of polymer engineering. The students are interested in the opportunity to make polymers with various degrees of toughness in the laboratory. Meanwhile, they understand that the sequence of lecture topics will eventually show the interrelationships among bonding, structure, and properties of substances.

Changes in the Lecture Portion of the Course

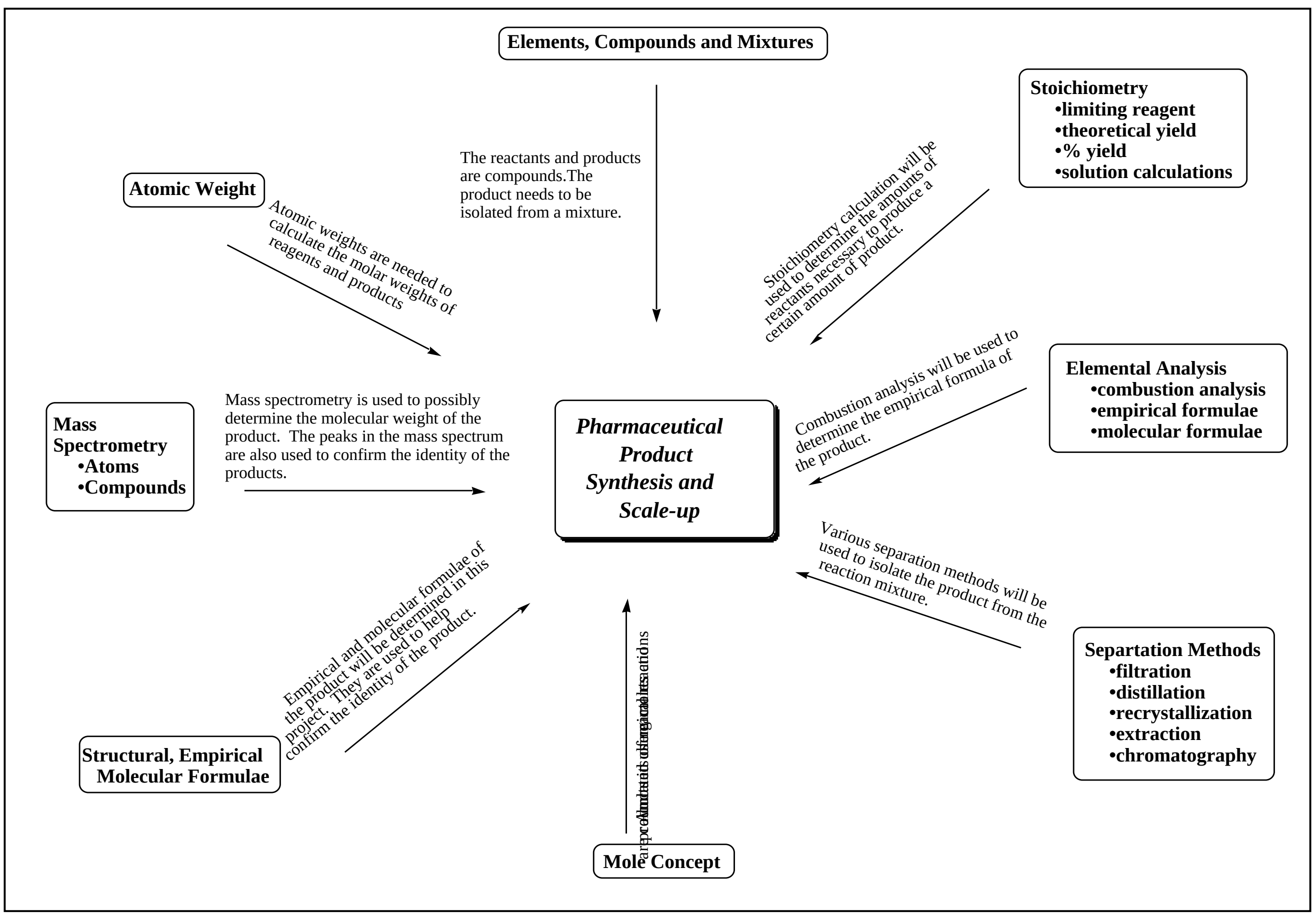
The lecture portion of the course is taught in a "mini-lecture" style in which topics are presented for ten to fifteen minutes, followed by in-class problem solving done individually or in student teams. During the first year of the Chemprojects curriculum, few changes were made in the lecture portion of the course except for a very brief (two to three minutes) mention of how an on-going Chemproject related to the lecture topic. Occasionally the professor mentioned that the laboratory was the most important part of the course because this is where they were learning to solve problems in an environment similar to that of professional scientists and engineers. We received many student comments indicating that they did not understand how the projects related to the course. More importantly, they were not seeing the relevance of General Chemistry concepts to engineering or other disciplines. These student opinions existed in spite of the fact that the professors, teaching assistants, and other faculty associated with the curriculum reform efforts understood all the connections between lecture and laboratory and between chemistry and other disciplines.

Changes were made in the lecture portion of the course to enable students to see the inter-relationships among the Chemprojects, General Chemistry, and other disciplines. The course began to be described as a laboratory-based course. References to the events in the laboratory were made several times during each lecture. The students were told that the lecture portion of the course was designed to help them learn material necessary to solve the problems posed in the laboratory. The percentage of the laboratory component of the course grade was raised to 40%. This was consistent with the large time commitment students devoted to the laboratory, both in the laboratory itself and at home.

Presently, the professor gives an overview lecture to introduce each Chemproject during the normal lecture period, explaining how the Chemproject is related to topics to be covered over the next three weeks. Efforts are made to make connections to the on-going Chemproject during every lecture, and sometimes multiple times during a lecture if possible. This may mean using examples related to the Chemproject. In the case of the Pharmaceuticals project, aspirin may be used as the model compound for a molecular weight calculation. Another pharmaceutical product, such as a sulfa-drug, may be used in a stoichiometry example. When the students complete a Chemproject and all the relevant topics have been covered in lecture, the professor reiterates the connections between all aspects of the project and the lecture topics by creating a concept map on the board. Figure 1 shows the concept map for the Pharmaceutical Product Chemproject. Students are asked to reproduce their own concept map individually during the post-project session. The students are then asked to work in their teams to recreate the concept map. In this manner, students see the benefit of working in teams because in most cases, the team concept maps are more complete.

Faculty from other disciplines, who had research efforts related to an on-going Chemproject, were invited to give guest lectures during the normal lecture period. An organic chemist involved in natural product synthesis discussed aspects of the pharmaceutical industry. A chemical engineer involved in emission reduction from coal burning talked about fuel research, and a mechanical engineer studying mechanical properties of materials discussed recent research efforts in tailoring polymer properties. This feature has two benefits. It introduces first-year students to topics related to their chosen discipline early in their academic careers. It also acquaints students with their future faculty in these disciplines.

Figure 1. Concept Map Relating Lecture Topics to Pharmaceutical Product Chemproject



These changes to the lecture portion of the course reduce the amount of time available for lecturing. We have chosen to place a premium on the time devoted to demonstrating the importance and relevance of General Chemistry principles to problems these students may encounter in their professions. Additionally, this relevance to their future profession, as well as the laboratory focus of the course, creates a "need to know" chemistry in the students. We use this motivational force as a resource to "buy back lecture time" by expecting the students to cover some of the simpler topics with less dependence on lecture. An example of the positive results from this "need to know" created in students is demonstrated by their request to eliminate pre-lab discussions and implement, instead, post-project discussions.

Student Teams

Students worked in teams of four during the laboratory. Several methods were used to assemble teams, with no noticeable difference in the results. First, students were asked to randomly

Table 2. Team Instructions for Week One of Enthalpy of Fuels Chemproject

Team Meeting Instructions
for
Enthalpy of Combustion of Fuel Mixtures Chemproject

Before Week One (This meeting occurs prior to the first laboratory session for this project).

Each student will bring the following items to the meeting:

- A one page summary of the assigned article on the sheet labeled "Individual Article Summary". (The project leader should have assigned an article to read when the Chemproject materials were distributed).
- A project plan

The project leader will facilitate the following events during the meeting:

- Pass around the team attendance sheet.
- Select someone to be the team recorder.
- Each student will read his/her article summary aloud to the team. The team will discuss the article after everyone has read his/her summary. The recorder will take notes during the reading of the summaries and the subsequent discussion. The recorder will draft a one-page summary of the team discussion about the article and fill out the sheet labeled "Team Article Summary".
- Each student will read aloud his/her project plan to the team. The team will discuss and finalize the planned steps necessary to accomplish the project goals. The project leader will take notes during this discussion. Individual tasks will be assigned for the duration of the project. The project leader will fill out the sheet labeled "Team Project Plan".

- The project leader will submit the following items to the teaching assistant at the start of Week One of the project:
  Team Article Summary followed by the Individual Article Summaries, paper-clipped together
  Team Project Plan followed by the Individual Project Plans, paper-clipped together.

assemble themselves in groups of four. Another semester, teams were selected based on students scores on a General Chemistry pre-test. A high and low scoring student were matched with two students in the middle of the range of scores. Finally, student teams are now randomly selected by having students pick a numbered piece of paper, labeled one, two, three, or four, from a container during the first laboratory session. Teams are assembled consisting of students with numbers one, two, three, and four. Sometimes teams of three are necessary. A dysfunctional team seems to occur every semester. Difficult team dynamics are handled individually by the teaching assistants in consultation with the professor. Oftentimes, the students in these teams are separated and left in pairs, or added to a team with missing members.

First-year students need to be taught to work effectively as teams. Teams are sometimes viewed as only a means to divide the work in the laboratory. It is important to structure Chemprojects and related assignments to avoid this pitfall. In particular, attention must be paid to insure that *all* team members complete calculations, data analysis, and interpretation. It is reasonable to expect some students to be better at data analysis. Ideally, these students should facilitate an improved understanding in other students by collaboratively working to reach similar conclusions.

Practices aimed at improving student team skills have been adopted during both the lecture and laboratory portions of the course. Some of our activities are adapted from a book entitled *Working Together: 55 Team Games* by Lorraine L. Ukens[37]. These activities have been modified to focus on General Chemistry concepts instead of trivia. They are sometimes done in lecture as follow-up problems to the topics presented. The exercise in which individual students and then teams reproduce concept maps for each Chemproject is another activity structured to demonstrate effective use of teams. Most recently, we have begun to provide the students with "Team Instruction Sheets" to better guide their team activities. Table 2 shows an example of these instructions for the first week of the Enthalpy of Fuels Chemproject.

Teaching Assistants

Proper training of teaching assistants in the methods of active learning, problem-based learning, and student-centered learning are crucial for the success of Chemprojects. In the future, we plan to implement workshops to instruct teaching assistants about these pedagogical methods, as well as all aspects of Chemprojects.

Traditional labs place teaching assistants in the role of "baby-sitter." Teaching assistants answer questions about procedures or calculations. Chemprojects place the teaching assistants in the role of facilitator or adviser. Students soon realize that there is no "right answer" known by the teaching assistants. This is initially disconcerting to the teaching assistants also.

Student Evaluation in Laboratory

Each Chemproject contributes one-third of a student's laboratory grade. Each project grade is determined from the rubric in Table 3. Team meeting reports are collected from individual students weekly. These reports require students to indicate at least two contributions they made to the group's experimental plan. Team project plans (2-3 pages) receive a team grade and are required prior to the start of each Chemproject. The project plans describe the experimental design to be implemented, including any necessary calculations. Teams meet weekly during a Chemproject to analyze initial data and discuss the assigned articles. During the laboratory students gather in "Data Analysis Group" which consist of one student from each team that worked with a different compound or fuel. The students answer distributed questions designed to show them how to graphically analyze and present their data. These group facilitate discussion about data from different teams. These data analysis questions are graded individually. The capstone assignment for each Chemproject is either an individual written report in the format of a scientific paper, an individual oral report, or a team poster given as part of a class-wide poster session. We have chosen these capstone exercises to be representative of the ways in which professional scientists and engineers communicate with their peers.

Table 3. Laboratory Rubric for Chemprojects Curriculum

Assignment	Component of Laboratory Grade
Team assignments (team grade)	10%
Scientific Paper (individual grade)	30%
Oral Presentation (individual grade)	15%
Posters (team grade)	15%
Individual assignments for team meeting (individual grade)	10%
Data Analysis Sheets (individual grade)	20%

Student Evaluation by Exams

The written exams in this course consist of three one-hour exams and a two-hour final exam. The exams consisted of problem solving questions which were *not* connected to the events in the laboratory during the initial stages of the Chemproject curriculum implementation. In order to reinforce the laboratory focus of the course the exam questions were structured to require understanding of similar concepts and calculations used for Chemprojects. The exam questions were also topically related to Chemprojects. Each hour exam was scheduled to occur near the end of a Chemproject when possible. Figure 2 shows the hour exam related to the Pharmaceutical Product Synthesis and Scale-up Chemproject.

Assessment of Student Learning

Eleanor Abrams and Anneliese Mueller of the Department of Education, and Christopher Bauer from the Department of Chemistry at the University of New Hampshire are overseeing assessment of the Chemprojects curriculum on student learning. These efforts include formative and summative evaluation methods. Pre- and post testing is being performed with attitude and science process skill instruments, as well as General Chemistry conceptual exams. Traditional laboratories are being run in between Chemprojects in order to observe student learning in this environment and compare it to student learning in Chemprojects. One laboratory session per week has been video-taped for the past two years to record how students spend their time during the laboratory. Selected students, student teams, and teaching assistants are being interviewed while enrolled in the course. We will interview select students for up to four years after they take General Chemistry to determine whether or not they see the Chemprojects experience as professionally valuable. The results of these assessment activities on student performance and attitude will be the subject of forthcoming publications.

Concluding Remarks and Preliminary Student Reactions

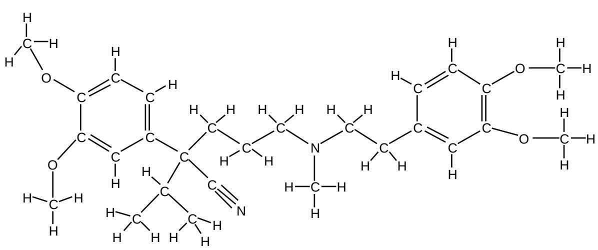
The Chemprojects curriculum has evolved steadily over the past three years. The current implementation that has been described in this article is the result of an iterative process in which we examine objectives, modify the curriculum, observe student practices, re-examine objectives,

Figure 2. Exam Related to Pharmaceutical Product Synthesis and Scale-Up

Chemistry 405 Exam 1, 9-25-98

PHARMACEUTICAL PRODUCTS

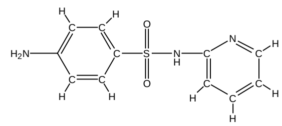
1. **(30 points)** Heart disease causes 37% of the deaths in the U.S. However, the death rate from heart disease has dropped significantly in recent years, partly because of the development of new drugs for heart therapy by chemists working in the pharmaceutical industry. One of these new drugs is verapamil. Verapamil inhibits accumulation of excess calcium in the muscle tissue of the heart by blocking transport channels for the Ca^{2+} ion. Calcium is essential for muscle contraction, but if concentrations are too high, proper relaxation of the muscle is inhibited. The structure of verapamil follows. A tablet contains 120.0 mg of verapamil.



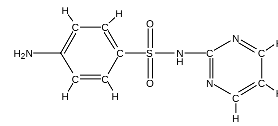
Verapamil

Determine the following quantities:
(a) the empirical and molecular formulas of verapamil,
(b) the molar mass of verapamil,
(c) the number of moles of verapamil in one tablet,
(d) the number of moles of nitrogen atoms in one tablet.
- What is the mass percent of each element in verapamil?

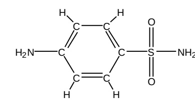
2. **(40 points)** Sulfa drugs were first discovered in the 1930's and became the first useful antibacterial drugs. These drugs suppress the growth of bacteria until the body's immune system can kill it. The structures of some of the most common sulfa drugs are shown below. You have attempted the synthesis of *one* of the compounds. You submit 5.00 mg of the sample to an analytical laboratory for combustion analysis, which yields: 7.674 mg CO_2, 2.093 mg H_2O, 1.8604 mg SO_2, and 2.674 mg NO_2.
(a) Determine the empirical formula for your product.
(b) Determine which of the following sulfa drug you have made based on the combustion analysis data. Be sure to show all work.



Sulfapyridine

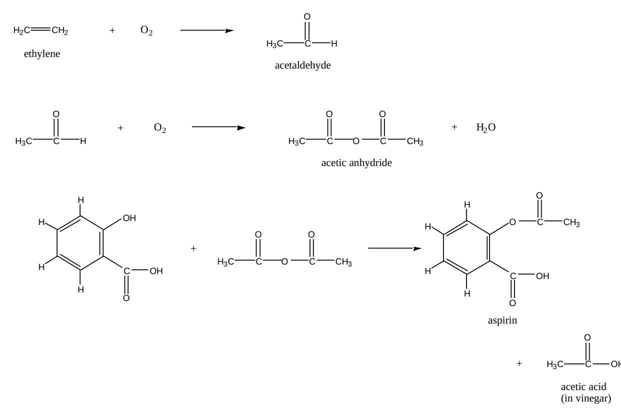


Sulfadiazine



Sulfanilamide

3. **(30 points)** Acetic anhydride is one of the reactants in the synthesis of aspirin. Acetic anhydride is made from two sequential reactions starting from ethylene, which is separated from natural gas. These reactions are given below.
(a) Write the overall chemical equation showing how ethylene reacts to form aspirin.
(b) Determine how much ethylene (in tons; 1 ton=2000lb; 1lb=454g) is needed to produce the 16,000 tons of aspirin tablets used annually by Americans. An aspirin tablet contains 325 mg of aspirin and weighs 0.5 grams.



re-modify the curriculum, and observe student practices. Table 4 shows a timeline for the progression of the Chemprojects curriculum.

For example, the first year's observation of student practices during laboratory revealed that student teams spend little time on discussion and interpretation of their data. Post-project discussion sessions led by a teaching assistant were introduced. These evolved into mini-lectures or question and answer periods. Instead, our objective had been to significantly increase the amount of time students spend graphing, studying data, and discussing its interpretation with each other. Therefore, "data analysis group meetings" have been implemented during the last sixty to ninety minutes of each lab session. These groups consist of one student from different teams, up to a maximum of three students. The students bring their own team's data to the discussion. The groups are provided with instructions that guide them through presenting graphs, describing and interpreting data, and forming conclusions. These exercises are collected from each student and contribute twenty percent to their laboratory grade.

Table 4. Timeline of Chemprojects Curriculum Modifications

	1995-96	**1996-97**	**1997-98**	**1998-99**
Fall		Implemented fuels project and poster session	Piloted 3 Chemprojects with 2 Traditional labs	Removed all traditional labs
		Proposal funded	Observations of students	Used examples and problems related to Chemprojects in lecture
			Observation of lecture	Made exams relate to Chemprojects in lecture
Spring	Began design of project-based lab	Modified fuels project	Added Post-project discussions	Added team instructions
	Discussions with engineering faculty	Testing of observation practices	Began to describe course as "laboratory-driven"	Added data analysis group sessions
	Proposal submission		Mentioned Chemprojects in lecture	
Summer		Developed Pharmaceuticals, Fuels, and Polymer projects	Developed Detergent and CVD projects	

This type of reflective pedagogy has been repeated until the Chemprojects curriculum fostered an environment in which students effectively practice: using General Chemistry concepts, experimental design and implementation, teamwork, data presentation, analysis, and interpretation, and communication of results in written and oral formats. Preliminary observations of student reactions indicate that our objectives are being satisfied and that students endorse these efforts.

The in-depth, professionally relevant nature of Chemprojects caused students to be more motivated during both the lecture and laboratory. Most students felt traditional labs were boring compared to Chemprojects. There was no resistance to meeting outside of lab; in fact, students deemed it necessary. At the beginning of each lab period, the teams immediately began discussing their plans and re-modifying if necessary. Students remain on task for most of the lab session. The teaching assistants fielded more varied questions, often procedural and open-ended. The students became more self-sufficient and realized there may not be a right answer. Students worried more about accuracy when required to formally present their work. Students solicited help on teamwork, such as conflict resolution. Students requested group post-lab discussion after each project. Table 5 contains student quotes that support our claim that student attitudes about Chemprojects have grown to be overwhelmingly positive over the past three years.

Table 5. Student quotes about Chemprojects

- "It gives a more realistic idea of what we will do in the future as a person in technology, working as a scientist in our field. It's funner—upscaling aspirin. In the group, everyone's way of thinking all combines. Everyone had their own idea of how we should approach the problem. Then we brainstromed and thought of one way that would be most effective."
- "I like working on a team. I'll remember how to make aspirin for the rest of my life. Instead of a regular lab where you just heat something up. It doesn't mean anything. Like well, who cares?"
- "I like the hands-on approach much better. We have more time to deal with stuff, more of a one on one with the TA."
- "I think it's a lot more effective than the traditional labs. If you have three weeks to work on a project, you can learn from your mistakes and make changes. In a traditional lab, if it doesn't work, it doesn't work."

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