2006-1399: SNEAKERS AS A FIRST STEP IN CHEMICAL ENGINEERING

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Abstract

Exploring Engineering is a required course for all first-year engineers at Bucknell University. This course provides students with an overview of the engineering disciplines, a first experience in engineering design, and an introduction to professional responsibility. Within this course, students elect to take three different three-week seminars, each focusing on a particular discipline. While these seminars provide depth in a given area, they must also contribute to the overall course objective: that students will develop an appreciation for the commonalities of all engineering disciplines.

"Engineering Athletics" is the chemical engineering seminar, in which students learn about polymer science, materials science, material balances and the design/manufacturing process within the context of designing a better sneaker. This paper describes the integrated series of classroom and laboratory sessions which comprise this project-based seminar. Briefly, student teams measure the material properties of a variety of commercially-available shoes. Students then develop a formulation for condensing solid rubber from liquid latex with the goal of producing a product that has properties which match or surpass those of polymers used in existing shoes. Finally, students attempt to "mass produce" this formulation to match specifications based upon the properties of their desired product.

This project is an excellent fit for a first-year course because it introduces key concepts in chemical engineering while emphasizing the interconnectedness of the engineering disciplines. Because many students are interested in sports equipment, the seminar works well as both an introduction for future chemical engineers and as a "taste" for those going on to other majors.

Introduction

Bucknell University is a primarily undergraduate institution with a focus on undergraduate education. The College of Engineering consists of approximately 700 undergraduate students, currently divided among six major fields (Biomedical, Chemical, Civil and Environmental, Computer Science, Electrical, and Mechanical Engineering). ENGR 100 is a course taken in the first semester of the first year by 210 students, comprising all incoming engineering students as well as interested students in the College of Arts and Sciences. The course is run in a modular format described in Vigeant et al [1-3]. The course format is summarized in Table 1.

The first course module introduces engineering and each of the six engineering disciplines taught at Bucknell and features a team-project where students suggest improvements to the Bucknell campus to enhance mobility for persons who use wheelchairs [1]. The second, third, and fourth modules consist of student selected, discipline related seminars. Eight different seminars are offered, each representing a different area of interest within the College of Engineering [2]. The small class-within-a-class format was adopted in the 2002-03 academic year, and continues to be the most positively rated part of the course in student surveys. The final module is devoted to engineering ethics.

Table 1: Course Timeline for ENGR 100: Exploring Engineering

Week #	**Module description**	**Content Summary**	**Lecture Class size**	**Lab Class size**
1 – 5	Engineering as a profession; design project on ADA compliance	Overview of engineering and each discipline	210	12-15
6 – 8	Seminar #1	Discipline related seminars	28	12-16
9 – 11	Seminar #2		28	12-16
12-14	Seminar #3		28	12-16
15- 16	Engineering and society	Ethics	210	21

The challenges inherent in creating one of the discipline-specific seminars are numerous. An informal, but very important, seminar goal is to create excitement about a given major. Students are to be introduced to technical content; however, they may not have completed any of the prerequisites required for major classes. Further, the content of the seminar may not be used as a prerequisite for any other course, because it cannot be guaranteed that particular students will have taken any given seminar. Eighty-four students take each seminar, while there are typically only about thirty chemical engineering majors. This means the majority of the students are not highly interested in chemical engineering. Finally, time is a significant constraint: all work must be accomplished within nine-class periods and three laboratory sessions (three weeks).

The “Engineering Athletics” chemical engineering seminar is our answer to this multiply constrained problem. The seminar is problem-based: student teams are given the task of designing and manufacturing a new, superior, material for sneakers. This problem is used as a vehicle to introduce several key areas of chemical engineering: basic chemistry, materials science, polymer science, mass balances, manufacturing/scale-up, and economic considerations. Each of these can be understood well using only high-school level chemistry and math, along with the several weeks of experience we know first-year students have in ENGR 100 and introductory physics. Informed by lectures on the topics listed above, students create a formulation for a latex polymer having properties they identify as ideal for a sneaker. Then students attempt to create and run a profitable factory where their product could be produced by operators (their classmates). Students demonstrate their learning via a quiz and a written project report.

Course Project and Content

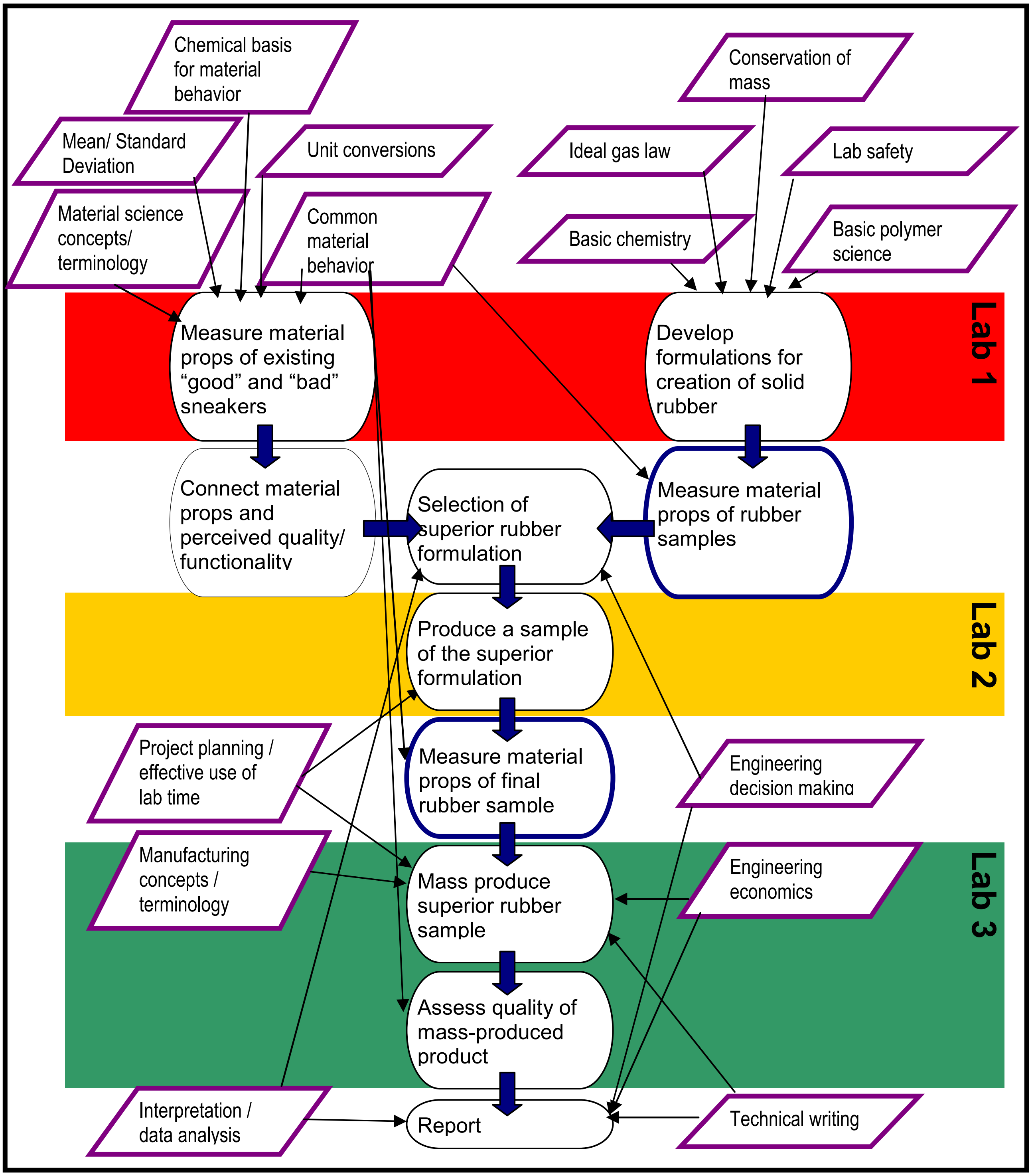
Table 2 lists the objectives for “Engineering Athletics”, their type, and the method of assessment used for each. The educational objectives for this seminar fall into three categories: technical, process, and overall. The technical objectives relate to definition of technical terms or application of equations. The technical objectives were selected by the instructor to give students an overview of chemical engineering at an appropriate level. Process objectives relate to the application of processes to the course material. For example, application of the formal "engineering decision making" process, a multi-step process discussed in class, falls into this category. Finally, this three-week seminar is part of a 16 week long course with its own overarching objectives which must be served by this seminar. Because this is one of three seminars an individual student will take, it is not expected that all overall objectives will be achieved.

Table 2: Seminar Objectives

Objective	**Category**	**Assessment Method**
Calculate mean and standard deviation for a data set; interpret results	Technical	Technical report
Define a set of materials science terms (ex: hardness)	Technical	Quiz; Report
Measure values for relevant materials science values (ex: hardness)	Technical	Report
Apply unit conversions	Technical	Quiz; Report
Describe the chemical basis for material behavior (ex: long chain polymers are stronger than those with short chains)	Technical	Report; Quiz
Apply the ideal gas law to predict vol. of gas evolved in rxn	Technical	Quiz
Apply basic chemistry concepts eg writing a chemical rxn	Technical	Quiz; Report
Apply conservation of mass (write a mass balance)	Technical	Quiz
Define basic polymer science terms; apply basic poly sci. concepts	Technical	Quiz
Use appropriate laboratory safety techniques	Process	Lab behavior
Apply an engineering decision making process	Process	Report
Use economic constraints in an engineered system	Process	Report
Define manufacturing terminology and use terms appropriately (ex: specification)	Technical	Report; Quiz
Use common sense in planning project work and allotting time for laboratory and analysis activities	Process	Lab behavior; Report
Interpret experimental data and draw appropriate conclusions	Process	Report; Quiz
Present results in an appropriately written document	Process	Report
Students will gain a better understanding of engr. disciplines	Overall	Survey
Students will gain an understanding of what different engineers do	Overall	Survey
Students will gain experience with open ended design project	Overall	Survey
Students will apply economic considerations to engr. systems	Overall	Survey
Students will appreciate the interconnectedness of engr. disciplines	Overall	Survey
Students will work on solving open-ended problems	Overall	Survey
Students will experience working on a multi-functional team	Overall	Survey
Students will be able to decide upon an engr. major	Overall	Survey

This seminar is driven by the project. Therefore the lecture and laboratory segments are highly intertwined. This is best explained by the concept map in Figure 1, which shows abbreviated versions of the educational objectives and how they relate to project activities. Objectives were discussed in lecture, and then reinforced by activities. Activities occurred in either the laboratory, class, or as homework. While many objectives are illustrated as impacting Lab 1 activities only, these foundational topics provided the basis for student progress through all remaining activities.

Figure 1: Concept map for "Engineering Athletics" seminar. Parallelograms indicate objectives (covered in lecture); rounded boxes indicate activities. Activities took place either in laboratory (colored bands), class (blue outlines), or as homework (plain black outlines). Thin arrows indicate where topics were applied, thick arrows show the time progression of the seminar.



Laboratory Experiments

The timeline of the three-week laboratory portion of the "Engineering Athletics" module is summarized in Table 3. Each laboratory section contained 12-16 students arranged in groups of four. For the first lab (Table 3, Lab 1) each group was further divided into two sections (pairs of students).

Table 3: Layout of laboratory timeline and deliverables

Laboratory	Deliverables	Notes
Lab 1 (Section 1)	• Understanding of how various combinations of raw materials affect the properties of the dry latex rubber product • Summary of individual experiments (formulation and mixing protocol) to be included in overall class summary • Characterization of latex samples (after drying for 24 hrs.)	
Lab 1 (Section 2)	• Comparison of properties of both "good" and "cheap" sneakers • List of ideal sneaker attributes	
Lab 2	• Develop a latex recipe to produce a rubber with ideal sneaker attributes • Design a manufacturing plan with regard to economic profitability • Establish criteria for manufacturing product specifications	
Lab 3	• In-spec products and quality control evaluation • Revenue-Cost Budget	
After Lab 3 (Final Report)	• Identify design/manufacturing challenges (e.g.– communication issues) • Overall profitability report	

The goal of Section 1 is to experiment with various formulations for making latex rubber and to characterize the resulting products. Solid latex rubber can be produced by mixing a dilute latex-ammonia suspension (commercially available from Flynn Scientific) with either 0.05-0.10 M acid or sodium chloride. The acid or salt disrupts the ionic strength of the suspension, allowing the latex chains to entangle and precipitate out of solution. Three different acids are made available to the students: 0.10 M sulfuric acid, 0.10 M citric acid, and vinegar (5% acetic acid). Additionally, a foaming agent such as baking soda (sodium bicarbonate) or baking powder (sodium bicarbonate + dry acid) may be added to produce the bubbles if a foamed rubber is desired. Other optional additives could include surfactant, oil, or excess water. The resulting solid latex product depends on the ratios of these components and on how they are mixed (e.g. – high shear, low shear, some components pre-mixed, over hot plate, over ice bath, etc.). The order of addition of raw materials may also be important. Each group pair is asked to generate eight different latex samples containing a constant amount of latex suspension (20 mL) and a variety of acids, foaming agents, and additives. After the samples are allowed to dry, the appearance, apparent elasticity, ductility, foam structure, resilience, hardness, strength, and any other relevant material characteristics can be assessed. A summary table of formulations, mixing protocols, and resulting properties for all samples is tabulated by the instructor and shared with the class.

Figure 2: A: Student working on latex production; B: Typical rubber products; C: Student team experimenting with latex formulation.

Meanwhile, the goal of Section 2 is to "reverse engineer" a sneaker. That is, by measuring the properties of existing "good" and "bad" sneakers, students are then able to develop the material characteristics that are ideal for their new sneaker. Students select a polymer component (sole or insole recommended) of two sneakers and perform eight material property tests as follows:

1) Elasticity (tensile test)
2) Resilience (metal ball bounce test)
3) Strength (tensile test)
4) Hardness (Type A durometer test)
5) Drag/Friction (spring scale test – Figure 3A)
6) Density (water displacement test and scale – Figure 3 B)
7) Viscoelasticity (compression recovery test)
8) Foam structure (observation after cutting – Figure 3C)

The motivation of Section 2 is that they are seeking out which material properties differ for good and poor shoes, by how much, and in what direction. As identical properties might be perceived as either "good" or "bad" depending on situation, teams are asked to identify an activity for which their sneakers will be used and assess all measurements within that frame of reference.

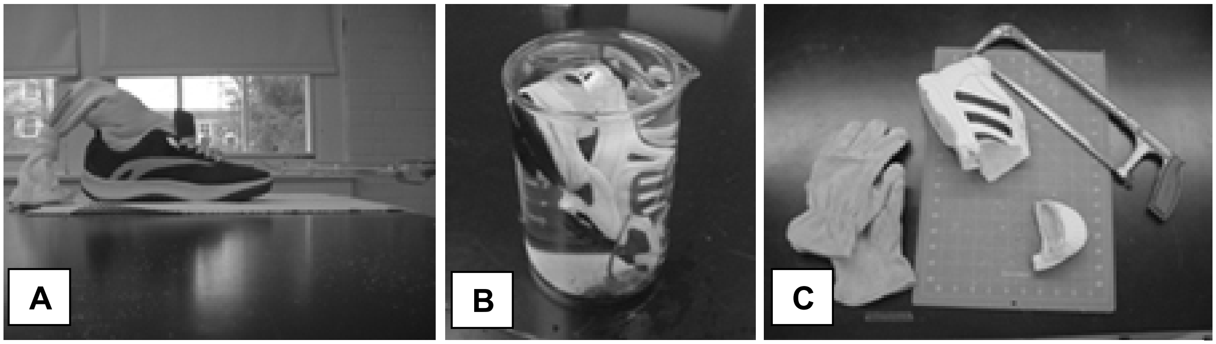


Figure 3: Laboratory tests to "reverse engineer" a sneaker. A: Friction test; B: Density test (typically done on small sample of sole rather than whole shoe); C: Shoe disassembly

Following Lab 1, teams are asked to identify, based on the measurements of existing sneakers and their own experience, the characteristics of an ideal sneaker for their activity. They then map characteristics (such as comfort) to material properties (such as hardness). Then, using their own judgment, they assign values to each of their shoes, their rubber formulations, and the formulations of other teams based on those criteria to form a decision matrix [4]. The rubber formulation with the highest score is their best product. Students are allowed to modify the formulation for this rubber based upon what they have learned in lecture (for example, how much acid is needed to completely react 1g of baking soda), and each team must agree on and hand in their formulation for a superior latex for their activity.

In the second lab, each group of four students tweaks their latex recipe and method to produce their superior product. In addition to finalizing their formulation, the students must also do any background work needed to accurately write a procedure for others to manufacture their superior product. The teams are given pricing information for raw materials, operating labor, and waste removal, as well as how much revenue they can expect for products within specifications as well as products that are off-spec. Based on their superior formulation and economic considerations, the teams develop specifications for their product, prepare a written manufacturing plan, and calculate how many in-spec. samples need to be produced to make a profit (Table 3, Lab 2).

During the development of the "superior formulation" students were deliberately not told of the raw materials / waste costs. This was to prevent them from placing a priority on price or manufacturability rather than quality. While it is a valid business decision to favor price, the chemical and material objectives of the seminar would have been compromised if students could neglect such considerations in favor of making a larger profit.

In the final laboratory meeting, students must attempt to make a profit by the production and sale of their product. This manufacturing segment was inspired by the work of Moll et al [5]. Teams enter the laboratory with a written procedure for either one or two employees. Since teams also calculate how many samples must be produced in order to make a profit as a pre-lab exercise, they enter the lab knowing how much of each raw material they plan to buy.

The timeline for the third laboratory meeting is detailed in Table 3. Each group is allowed fifteen minutes to set up their glassware and to purchase raw materials at cost from the instructor. After this time, two students from each group are randomly selected to serve as operators for another group, while the two remaining students become managers, representing their own design team. Each team is then allotted five minutes to train their operators to perform their specific procedure. At the end of the training period, the manufacturing process begins. The management team observes their operators, without communicating, and records the success or failure of how the operators interpret the written manufacturing plan and oral training instructions. Finally, after ten minutes, the quality of each product is measured against its specifications. Teams then compute the total costs and revenue for their process and determine their overall profit and assess what they could have done better in the final report.

Table 4: Timeline for laboratory 3

Time Allotted	Objective
15 Minutes	Setup latex “plant” (glassware), Buy raw materials
5 Minutes	Train Operators
10 Minutes	Manufacturing Time
Unlimited	Quality Control Assessment

The content of the final written report described the two main outcomes from the project: 1) What is the team’s superior latex formulation and did it match their predictions and 2) Did their manufacturing process return a profit, and why or why not? For each outcome, teams were required to provide background and data documenting how their decisions were made, and to review what they did to see if it could have been improved.

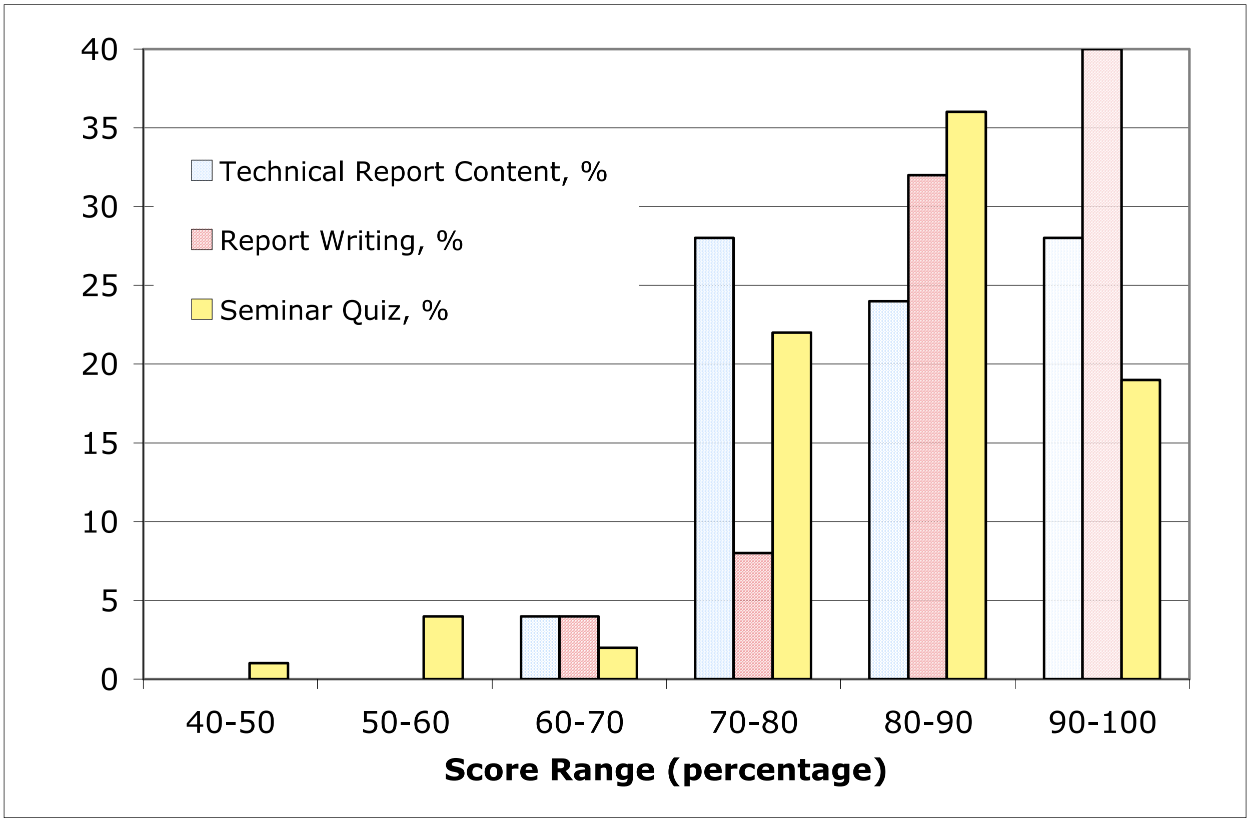
Figure 4: Students working in the laboratory.

Results and Discussion

The success of this seminar may be assessed in three ways. First, do exiting students meet the objectives of the seminar? Second, does the mini-course meet the affective objectives for the overall course? And finally, what impact does this seminar have on first-year students’ enrollment in chemical engineering as a major?

Students attainment of the technical seminar objectives is assessed both through the grading of their project report (a team effort) and by a final quiz (individual). The grades on the report are further broken down into a grade for technical analysis (use of engineering judgment, economics, chemistry, etc) and technical writing (clarity of prose, organization, etc). Which objectives are assessed by each method is shown in Table 2. Histograms for each of these three elements are shown in Figure 5. The vast majority of students scored acceptably (at least a 71%) on all three assessment elements. Therefore, we can conclude that, overall, the seminar objectives were met.

Figure 5: Student scores on all assessment methods, tabulated for each individual



The overall course objectives as applied to this seminar are affective in nature and are therefore assessed by survey. The survey was given to a subset (n=28) of the seminar participants and the results are shown in Table 5. All overall objectives were attained at a satisfactory level but for the last, helping students decide upon a major. This question had the widest response distribution of all of the questions and is probably the trickiest one to assess. While it is an overall course objective to help students decide upon a major, fewer than 1/3 of the arriving first-year class was undecided about their major. Therefore, one would expect the majority of students to respond either “neutral” or “disagree” on question 8 (Table 5). A future improved assessment of this particular objective would be to limit the question to only those students who were initially undecided.

Table 5: Effectiveness of reaching overall course objectives as implemented in this seminar

Question	Mean	Mode
1. This seminar gave me a better understanding of chemical engineering	4.3	4
2. This seminar gave me a better understanding of what chemical engineers do	4.2	4
3. I gained design experience in this seminar	4.3	4
4. I have a better understanding of the impact of economic considerations on engineering after this seminar	4.2	4
5. I have a better understanding of the interconnectedness of engineering disciplines after this seminar	3.9	4
6. I gained experience solving an open-ended problem in this seminar	4.1	4
7. I gained experience working on a multi-functional team in this seminar	4.0	4
8. This seminar helped me decide upon my major	3.4	3

5= Strongly agree; 4 = Agree; 3 = Neutral; 2 = Disagree; 1= Strongly Disagree

A final measure of the seminar would be if it had any impact on the number of students enrolling in chemical engineering as a major. Students may start their first year either in a major or undecided, but then must declare a major before the end of the first semester. For the Fall 2005 first-year class, 32 arrived as chemical engineers, and by the end of the semester first-year chemical engineering enrollment reached 40 students. This level of recruitment/retention is consistent or better than the previous two years, indicating that the seminar is not negatively impacting retention in the major.

Instructor observation indicates that this project was interesting for the students and appeared to accomplish its objectives. Small modifications in the overall presentation were suggested by our observations. The costs of materials for the manufacturing segment warrants attention: none of the student teams was able to turn a profit, even though the prices of raw materials were decreased for each subsequent seminar. The most common complaints were about the salary of the operators and the cost for waste removal. In the future, we will introduce these as considerations during Lab 1, so that initial formulations can take these factors into account. Several student managers commented that their job was “frustrating”, which encouraged them to critically assess their work. These students went on to show in their reports that they realized their instructions, while perfectly clear to them, had critical gaps when read by others. In the future, we will work to help students learn this lesson without it necessarily sabotaging their profit.

Conclusion

A three-week seminar based upon “Engineering Athletics” was presented to first-year students in order to introduce them to chemical engineering. The seminar consisted of nine one-hour class meetings and three two-hour laboratory sessions. Students in the seminar were a mix of both those who intended to major in chemical engineering and those intending to study other engineering disciplines. The main thrust of the seminar was an open ended project in which students attempted to design a material to be used in the manufacture of sneakers. Students measured the properties of existing sneakers, experimented with different formulations for producing latex, measured the properties of the resulting latex, determined the characteristics and formulation for a superior latex product, and finally attempted to manufacture that product. In order to accomplish this project, students learned about materials science, chemistry, mass balances, and other fundamental chemical engineering concepts. Assessment shows both the technical and affective objectives of the seminar were accomplished. This seminar should be portable to other institutions, or with some modification, could be used in outreach activities with high school students. We plan to use this seminar again in the coming academic year.

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