2006-1454: PROJECT-BASED LEARNING IN A FIRST-YEAR CHEMICAL ENGINEERING COURSE: EVAPORATIVE COOLING

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Abstract

The challenges of engaging first-year engineering students are well known. Many students come to an engineering curriculum poorly prepared and with substantial misunderstanding of what engineers actually do. Too frequently, recent high-school graduates are unprepared to make the commitment to do the hard work required to complete their degree in four years. Some students who might otherwise become successful engineers change their major to one that has more immediate appeal, is an easier pathway to graduation, or is taught by instructors who address the students' preferred learning styles directly.

At engineering colleges around the country, many inventive programs have recently begun to address these issues[1,2]. Along with recognition that the traditional lecture-based format is far from ideal, many programs and departments have created innovative problem-based-learning first-year courses[3,4]. The perception is that giving students the opportunity to design, build, and test a "widget" will engage them more fully, motivate them to study harder, make a more educated choice of major, and commit to the major. Students whose preferred learning style requires active, hands-on activity discover that engineering may suit them well, in contrast to what they may have concluded from lecture-based courses.

This paper is a report on one such effort at the University of Nevada, Reno, funded by the Hewlett Foundation. A new course has been developed in chemical engineering with a green-engineering theme, and uses a project as a vehicle to learn teamwork, to practice engineering design, measurements, and graphical data representation. We also address academic study skills and use Felder's Index of Learning Styles (ILS) to enable students to be aware explicitly of their own learning style.

The project is to design, build, and test an evaporative cooler, and is conducted in teams of 3 or 4 students, that endure for the semester. Assessment criteria include evaporative cooler performance, cost, safety, and style. Safety is given prominent focus repeatedly throughout the semester. Students learn how to use a psychrometric chart and apply it to rate the performance of their cooler. The nature of measurements is discussed. Teamwork skills, including problem solving, are addressed. Students practice engineering design in a formal manner, with several repetitions of design versus performance, safety audits, and cost playing important roles.

The class incorporates several teaching methods, to target learners of all types. Sensors benefit directly from the project, and seeing the results of their work, while intuitive learners do well with the performance calculations, and also with the varied engineering calculations included in the text by Solen and Harb[5]. Visual learners do well with the psychrometric chart and the design diagrams, while verbal learners gain from the classroom discussions and from the book reading. Active learners especially benefit from the incorporation of this project, since it requires hands-on building in a group. Reflective learners profit from writing the reports and completing the homework assignments. Both inductive and deductive learning styles are

incorporated, since the nature of evaporative cooling is understood by all at some intuitive level, and we analyze the cooling by looking at rates of heat transfer, mass transfer, and thermodynamics. Finally, iterative design benefits both sequential learners and global learners.

The project component of the class has been through two iterations, once in the summer of 2005, and again in the Fall of 2005. Preliminary results suggest strong student buy-in to the project. Disadvantages of the project include weather (geography), cost, and for some students, the discomfort of working with their hands for the first time.

Introduction

Many reasons are given for incorporating project-based learning (PBL) in first-year engineering (FYE) courses[1,6]. Perhaps the most significant are related to student retention. PBL gives students the opportunity to work in groups and form bonds. Students who have formed relationships with other students and especially with faculty are much less likely to drop out of engineering[1]. PBL addresses learning styles quite distinct from those addressed in more traditional lecture courses. For example, sensory learners and active learners may feel left out in a lecture course, while PBL includes sensing and active learning directly. Substantial literature indicates that students often leave engineering curricula because of the failure of engineering courses to address their learning styles[7].

In 2003, a 5-year $1.1M project was funded by the Hewlett foundation for enhancing engineering education. It includes several components, one of which is creating new discipline-based and multi-discipline FYE courses. To this point, three different courses have been created, the most recent of which is in chemical engineering. Each of the FYE courses have several common objectives: to develop written and oral communication skills; to familiarize students with the engineering design process through a hands-on semester-length project; to develop teamwork skills; and to develop basic computer skills.

At UNR, ChE 101 is a 3-credit course required in the first semester of the chemical engineering curriculum. It has 3 weekly meetings: a 3-hour meeting on Monday afternoon; a 1-hour meeting Thursday morning, and a 1-hour seminar with all undergraduate chemical engineering students on Friday. The course has been taught for several years, more or less following the text by Solen and Harb[5], and supplemented with guest lectures, a couple hands-on short experiments, and often a plant tour. The course typically has about 25 – 30 students enrolled, and typically suffers a high DFW rate (final grade of D, F, or W for withdraw.) For the redesigned chemical engineering FYE, a few objectives were added to those listed above for all the UNR FYE courses: to introduce the field of green engineering; to develop the study skills necessary to succeed in chemical engineering; and to practice engineering calculations. From the beginning, the course is designed to enable students to succeed in

Table 1 Following is a list of course goals, each with a corresponding learning objective.

1. Develop successful study skills;
2. Introduce green engineering;
3. Gain practice in engineering calculations;
4. Build interest level in chemical engineering;
5. Develop communication skills;
6. Practice engineering design;
7. Develop teamwork skills;
8. Develop basic computer skills.

chemical engineering, and to motivate students to want to succeed in chemical engineering. Table 1 summarizes the course objectives. Four students enrolled during the summer of 2005, and 39 students enrolled during the Fall 2005 semester.

A focus of green engineering was selected due to anticipated student appeal. It was thought that green engineering might appeal to a broad swath of first-year students, not just chemical engineers. As a result of much searching and many conversations, we concluded that a project related to the design and construction of an evaporative cooler (a "swamp cooler") would be suitable for this class. It turns out that the state of Nevada has recently experienced a substantial increase in electrical power usage, much of which is directly attributable to air conditioning usage statewide, but primarily in Las Vegas. A swamp cooler uses much less electrical power for equivalent cooling than traditional air conditioning, and the reduced electrical power consumption might be connected to green engineering.

Table 2 Summary of Learning Styles Inventory questionnaire results. Each entry represents the number of students who reported that particular learning style.

Active	Reflective
17	18
Sensing	Intuitive
25	10
Visual	Verbal
27	8
Sequential	Global
24	11

About five weeks into the semester, students completed the web-based Index of Learning Styles as a homework assignment[8]. The results are summarized in Table 2. The broad distribution of learning styles represented in the course is surprising, and reinforces the importance of PBL and other active learning and teaching methods. Each of the eight learning styles can be found in the class, and for each style, there was at least one student in the class who displayed a strong preference.

The assignment

Three topics were introduced at the onset of the assignment: safety, the psychrometric chart, and engineering design. The importance of safety is obvious to practicing engineers, but is certainly not obvious to first-year engineering students. The repetitive nature of engineering design, as illustrated in Table 3, was presented in class, and contrasted with "The Scientific Method", something most of the students were quite familiar with. The nature and utility of the psychrometric chart was discussed in class, and related homework problems were assigned. Each of these three themes were discussed repeatedly in class throughout the duration of the assignment.

Table 3 Engineering Design Method

1. Identify the problem & constraints
2. Brainstorm various solutions
3. List previous or similar known solutions
4. Evaluate possible solutions subject to known constraints
5. Design prototype
6. Build prototype
7. Test prototype
8. Evaluate prototype (Cost, safety, performance, etc.)
9. Revise design
10. Modify prototype
11. Test & evaluate prototype
12. Repeat steps 9, 10, & 11 until complete
13. Documentation- Without talking to you, how can someone: (a) use your innovation; (b) build another one?

On the first day of class, students were given a survey to complete (Figure 1). The answers were used to form ten groups of four students apiece. There were several criteria for forming groups. First, we tried to ensure that students live nearby each other, and that each group had at least one member with some familiarity with using hardware tools. We tried to ensure that all members of a group had common meeting times. And no women were put onto a team individually, always in groups of at least two. In the summer course, this was quite straightforward, but in the Fall course, with 39 students, it was quite difficult to actually follow each of these constraints.

Table 4 Project assignments

1. What is a swamp cooler? How does it work?
2. Brainstorming and safety.
3. Preliminary design and likely budget.
4. Assembly and preliminary testing. Oral presentation.
5. Design modifications.
6. Cooler performance analysis.
7. Cooler demonstration and oral presentation.
8. Final report.

The project had eight assignments and due dates, sprinkled throughout the semester, summarized in Table 4. In each assignment, safety was included, usually explicitly. In the first assignment, students were given a detailed format to follow, since this was the first college-level group assignment completed by most. They were asked to describe what a swamp cooler is, to give a typical design, and to formulate a standard test for evaluating the performance of a swamp cooler. Students were also asked to identify potential hazards of the swamp cooler operation and construction.

Before the second assignment, each team was issued a fan, a GFCI power cord and outlet for safety, and a portable humidity and temperature probe. The fans were of various sizes and designs, but typically 12", designed for substantial air throughput. Each team was asked to use engineering terms to describe the fan operation (air flow, power, speed, etc.), to brainstorm methods of bringing air and water into contact. For the third assignment, students were asked to provide a preliminary design, including sketches, budget, parts, assembly process, and to describe how they would access the required tools. No access to hardware was given.

The fourth assignment was a major milestone, and required teams to prepare a 3-minute presentation on the design and performance of their coolers. Few students in the class had previous experience with PowerPoint, and it was challenging for them to produce a talk. Each individual in the class evaluated each talk, giving written feedback to their classmates. This had the benefit of letting students benefit from the "best practices" of their classmates, and resulted in *much* improved subsequent presentations. At this point, the teams' productivity and performance were quite varied; two teams had only a preliminary design, and several had working prototypes. The sharing of "intellectual property" between teams at this point was greatly appreciated, and facilitated much improved designs. At this point, no team had a cooler performance greater than about 50% maximum cooling, but this set a sort of benchmark. Part of the fourth assignment required the teams to identify planned design modifications, and to evaluate the impact on cost, performance, and safety of the modifications.

The fifth assignment essentially required repetitive performance analysis, and to identify additional modifications. It also required students to conduct a two-hour test. The sixth assignment was similar, and also required the cooler's performance be shown graphically on a psychrometric chart. Students brought to class the finished coolers for a demonstration of its operation, and each team gave a 10-minute presentation for the seventh assignment. The coolers were graded based on performance, safety, budget, style, and team work. Performance was determined by the degree of moisture saturation, as well as the ability to calculate that efficiency properly. Safety and team work were graded by the presence or absence of visible problems.

The last assignment was a detailed final report, with three sections. The first section required a narrative of how the initial design changed into the final design, and a detailed performance analysis. The second section required either a user's manual or a detailed procedure of how to build a cooler identical to their teams' cooler. The last section was called an environmental report, and required students to compare their cooler with an equivalent air conditioner. Students were intentionally given no guidance on that part.

Results

Overall, students participated in this project with relatively high enthusiasm. With a single exception, all assignments were submitted on time, which for a first-year course, is a substantial achievement. Each of the eight assignments showed improvement over the previous submissions in terms of quality of writing, group cohesion, and swamp cooler design. No substantial safety violations occurred. Surprisingly, all groups completed the project with a budget of less than \$100, and a couple finished spending less than \$40.

With regard to defining and calculating cooler efficiency, most students had some difficulty understanding the intrinsic nature of the calculation. For example, some used merely the outlet temperature, or the outlet humidity of the cooler, ignoring the temperature (or humidity) change. Initially, nearly all students had trouble grasping the concept of the maximum temperature change, and the corresponding maximum increase in humidity, according to the psychrometric chart. After the class agreed on a single definition of efficiency (the ratio of actual cooling to maximum cooling) there were still problems using it. For example, some students measured the room temperature, rather than the exit temperature, and erroneously concluded that the efficiency was increasing over time. This difficulty was surprising, since the students solved for homework simple problems requiring the use of the psychrometric chart, indicating that perhaps they had only a superficial understanding of the chart.

The final cooler designs were somewhat varied, but all featured forced air flow, recirculating liquid water, and a wetted membrane, and all but one included a closed chamber. See samples in Figure 2. The significant differences in design were in the material used for membrane, and whether the fan was oriented to draw air into the chamber or to force air out of the chamber. Some used multiple membranes, and the water distribution assembly was unique for each case. Final efficiencies were mostly in the range of 50% - 70%.

The students were notified well in advance of the final presentations that the top three would be selected to give their presentation at that week's undergraduate seminar. Although this may seem intimidating for first-year students, the competition was fierce, since three points extra credit toward the final grade was offered as incentive. In all cases, the quality of the oral presentations increased dramatically between the first and second presentation, a time period of eight weeks. Students mimicked the better presentations given by their classmates to improve their own presentations. The students also benefited by giving feedback to the presenters, forcing them to think in a different way about their own presentations.

Assessment

The success of this project in achieving the goals outlined above is assessed through several means. Students were asked to evaluate each of their teammates using a standardized form to diagnose teamwork effectiveness. Final course grades and registration in subsequent courses gives insight into student persistence, and reflects retention. Student feedback was solicited on several occasions.

A distribution of final grades for the two 2005 groups, using PBL, is shown in Figure 3, along with a distribution of grades from the same class taught in Fall 2004. The average course grade in 2005 was 2.86, and 2.58 in 2004. Note that many variables affect final grades, not just the course project. The instructors were different, also. The distribution is not terribly different, but there is a higher rate of "A" grades earned and awarded in 2005. There was also a much higher rate of "D" grades earned and awarded in 2004. Six of 41 (15%) students got a "D", "F", or "W" in 2005, while nine of 30 students (30%) got the same designation in 2004.

In the second semester of the curriculum, students complete ChE 102, which lists ChE 101 as a prerequisite. Some insight into persistence in the major might be found by examining the enrollment of students in the semester after completing ChE 101. Note that these two courses are more frequently than other courses taken out of sequence, in an effort to accommodate students who change the major in their first year of study. So persistence rates reported here reflect only students enrolled in ChE 102 in the semester *immediately following* the semester they completed ChE 101. Table 5 shows that the first-year persistence rate has been increasing in chemical engineering at UNR for the last several years, and for the 2005-06 academic year, is up to 66%. Please understand that this is *not* a retention rate, but might well be correlated with the retention rate, however it is defined.

At the end of the term, students completed an anonymous questionnaire, as is usual practice on most university campuses. In response to the question "Throughout the semester, we'll learn about the engineering design process through an example, building a swamp cooler." 25 students indicated that they thought this objective was well met, while only 3 indicated that it was not well met. 24 students indicated that teamwork skills had been enhanced through the project, while only 3 didn't agree. 33 students thought that the objective related to engineering calculations was well, met, while only 1 student did not agree. 17 students agreed that the

Table 5 First year persistence rate, defined as the number of students who enroll in ChE 102 in the semester immediately following the semester they completed ChE 101.

Academic year	Persistence rate
2002-03	48%
2003-04	41%
2004-05	62%
2005-06	66%

course objective related to green engineering was achieved, while 2 did not. In response to the question "What is your overall rating of the *course*? (1) means poor, (3) is satisfactory, and (5) is excellent.", the mean response was 3.71, and the median response was 4.0. Certainly, for a first-year course, this response is rewarding, and more so for a first *term* course.

Twice, students were asked for written comments on the term project: once on the final exam, and once at the end of the project, about two weeks before the end of the semester. Students were asked to give both positive and negative feedback, since their feedback would affect next year's students. A great deal of the feedback was positive, and with only a few exceptions, most enjoyed the forced nature of the group work. For example, "I liked that you assigned the groups rather than us picking because it forced everyone to work with new and different people." A couple groups indicated some trouble scheduling team meetings, and with two groups, that problem was severe. Several teams were comprised of all members who live in dormitories on campus, and several of those teams complained about the difficulty in accessing hardware. The following complaint was typical: "It's hard to expect that a group who all lives in the dorms can build as powerful and efficient of a swamp cooler as a group who has access to a garage and tools." It might be noted, however, that this additional burden brought about some substantial creative designs. For example, one team used only a glue gun and a box cutter for building their cooler. Some students suggested using more class time for the actual construction and testing process: "It would be nice to use the 3 hour class period as a chance to work on our projects, because it was difficult to meet sometimes." Several indicated that they thought the structured format was beneficial, such as "I thought the numerous reports we had to make really helped our design stay on track." Several indicated that they wanted more of an event for the final demonstrations of their completed projects. This indicates that they felt as if they'd achieve something truly significant, worthy of some fanfare.

Several indicated that they wanted more guidance on how to design an evaporative cooler, and would have preferred detailed drawings of common designs. Quite a few students remarked that they saw no connection between the project and chemical engineering. It's interesting to note that both these complaints clearly indicate that the students have a long way to travel in the transformation from high-school student to chemical engineer. Hopefully, the project left the students with a better understanding of design and chemical engineering, although somewhat frustrated!

Recommendations

Overall, this project was a success, but there is certainly room for improvement. The next time around, some class time will be dedicated to the project. Students will be invited to the unit operations lab, where teaching assistants and the professor will be available for assisting the students with the project. Some simple tools will be available at that time. We'll try to make tools more accessible by ensuring that at least one member of each team is from the local area, so that even if all the team members live in the dorms, they might have access to a house nearby.

This project works much better in a desert climate, like Reno, than elsewhere. Even in Reno, though, the ability of a cooler to humidify outside ambient air is much reduced from October until perhaps early June. Thus, much of the testing was done indoors. A small dorm room is very quickly saturated to 100% humidity. However, our unit operations lab has substantial air exchange, and even with 10 coolers running simultaneously, the humidity increased from 30% very little. The value of this project is certainly geographically constrained.

Finally, we note that the final demonstration might be done as more of a showcase, so that the students feel like their hard work is recognized. We anticipate having some advance publicity and prizes at the project conclusion.

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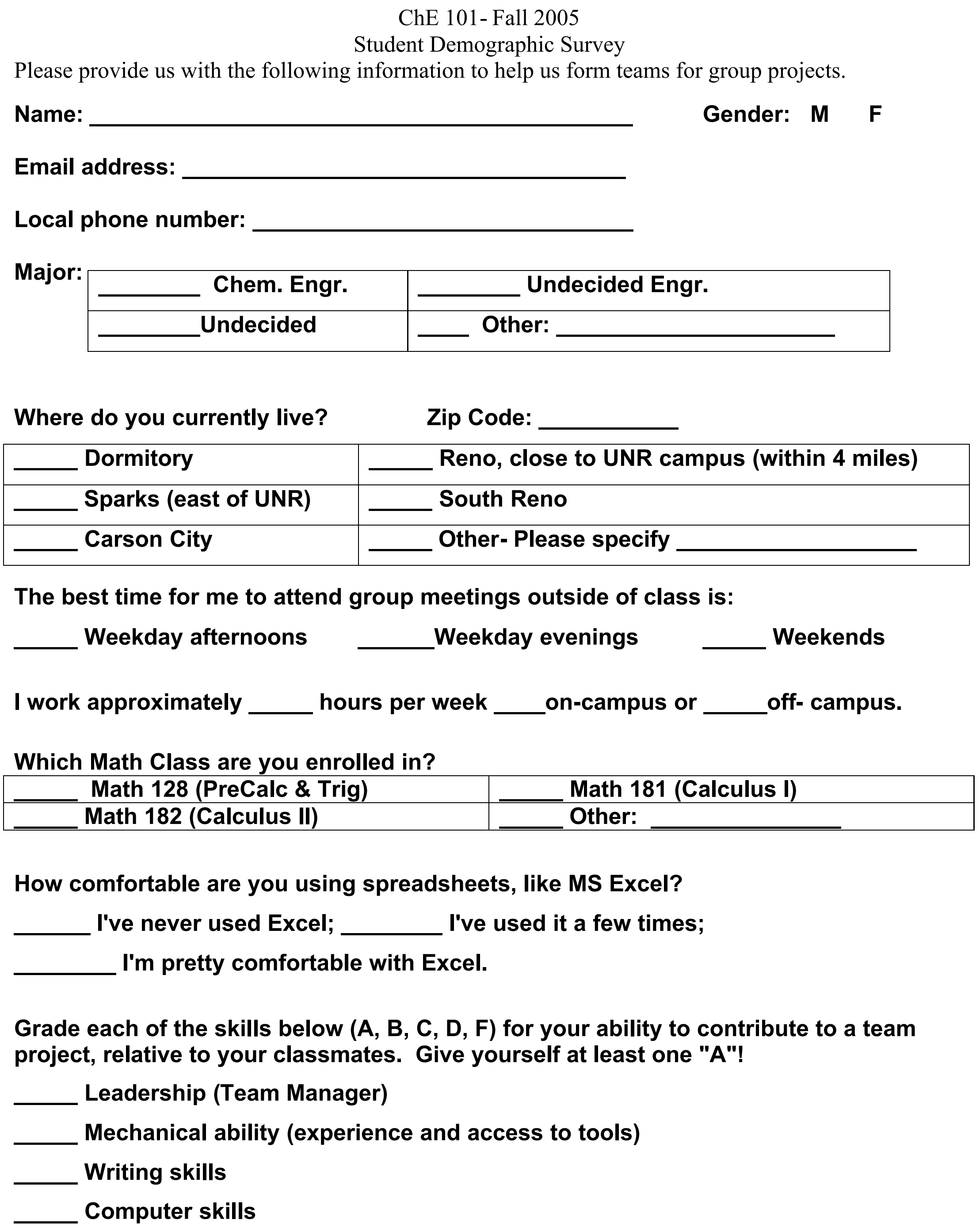

ChE 101- Fall 2005
Student Demographic Survey
Please provide us with the following information to help us form teams for group projects.

Name: ______________________________________ **Gender: M F**

Email address: _______________________________

Local phone number: __________________________

Major:

________ Chem. Engr.	________ Undecided Engr.
________Undecided	____ Other: ______________________

Where do you currently live? Zip Code: ___________

_____ Dormitory	_____ Reno, close to UNR campus (within 4 miles)
_____ Sparks (east of UNR)	_____ South Reno
_____ Carson City	_____ Other- Please specify __________________

The best time for me to attend group meetings outside of class is:

_____ Weekday afternoons ______Weekday evenings _____ Weekends

I work approximately _____ hours per week ____on-campus or _____off- campus.

Which Math Class are you enrolled in?

_____ Math 128 (PreCalc & Trig)	_____ Math 181 (Calculus I)
_____ Math 182 (Calculus II)	_____ Other: _______________

How comfortable are you using spreadsheets, like MS Excel?

______ I've never used Excel; ________ I've used it a few times;

________ I'm pretty comfortable with Excel.

Grade each of the skills below (A, B, C, D, F) for your ability to contribute to a team project, relative to your classmates. Give yourself at least one "A"!

_____ Leadership (Team Manager)
_____ Mechanical ability (experience and access to tools)
_____ Writing skills
_____ Computer skills

Figure 1 Demographic survey distributed to students for forming groups.

Figure 2. Three samples of the finished swamp coolers designed and tested in Fall, 2005.

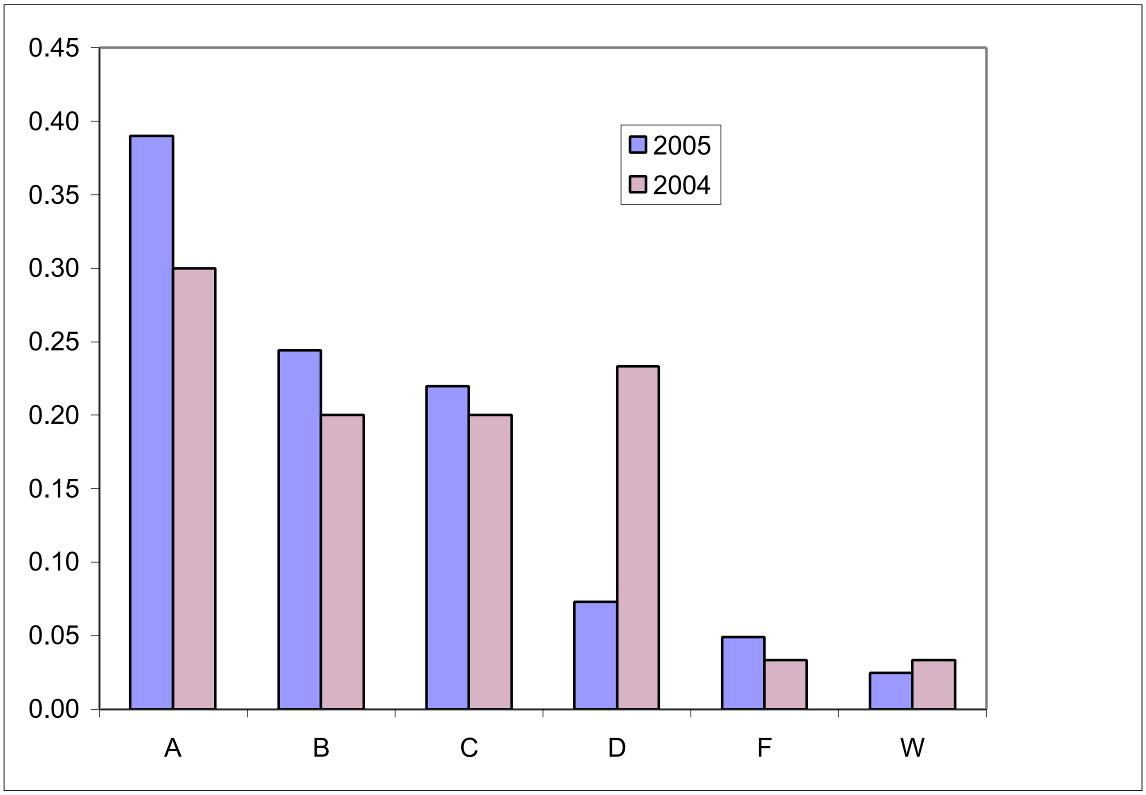

Figure 3. Distribution of final course grades for ChE 101 in 2004 and 2005. Plus and minus grades are lumped in with the unqualified letter grade. There were 41 final grades in 2005, and 30 final grades in 2004.