FRESHMAN DESIGN COURSE FOR CHEMICAL ENGINEERS

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Freshman design courses are problematic because students do not yet have the fundamental engineering background necessary to solve real problems. Yet, for students to be "caught" by the excitement of an engineering career, they must experience the thrill of understanding a problem, of using a rational approach to create a solution, and finally, of watching the public enthusiastically receive that solution. In chemical engineering, this becomes difficult because we do not traditionally make "widgets." We make processes, and frankly, flowsheets are just plain boring.

Chemical engineering in academia is quite abstract, and yet many problem solutions benefit from the capabilities of practical minds. One departmental goal is to intrigue and retain students who learn and work with practical styles. Studies have shown that women enter engineering because of high-level mathematical skills, but leave with very low self-esteem, in part because they have little hands-on confidence.[1] Therefore, it is also critical to help the abstract thinkers gain self-efficacy through hands-on experiences.

At Colorado State University (CSU), each department begins its core course sequence in the freshman year. The goals include developing a sense of belonging among the students, familiarization with the campus facilities, and building close personal relationships between engineering faculty and new students. The freshman core in each department consists of a one-semester programming course and a one-semester design course. The chemical, agricultural, and environmental engineering students are grouped into one class of 60-85 students. There are no pre- or co-requisites, and the course is meant to give very basic skills as a foundation for the sophomore fall course on mass and energy balances. Students are allowed to substitute design course credits from another department should they choose to change majors.

COURSE DESCRIPTION

Chemical and Bioresource Engineering 102 is a three-credit freshman design course. The students use classical design steps to build a lab-scale pilot plant that solves an open-ended process design problem. The pilot plant must be safe to operate, require minimal lab space and machine-shop time, cost less than $10 per student, be used by the public at Engineering Days (E-Days), and demonstrate chemical engineering principles. It is the professor's challenge to identify a problem difficult enough to be solved in at least fifteen unique ways.

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The course maximizes structure within the design process and creativity within the laboratory. It is taught in a way that integrates the traditional and modern approaches, as defined by Dym.[2] Students are required to take each step in the design process, from material characterization through prototype testing. At the same time, they are required to develop their own laboratories associated with each of these steps. The text, *Design in Agricultural Engineering* (by Christianson and Rohrback) is used as a reference when discussing the design process. While the text content is directed more toward objects than processes, the design concepts apply directly to any type of a problem. One goal of the course is to have students learn that design results from a rational progression of thought and action.

The skills that the students must learn in this introductory course are: methods of measurement, remedial statistics, computer graphing packages, computer drawing packages, word processing, computer spreadsheets, lab notebook management, engineering drawing, time management, team dynamics, product design, product testing, failure analysis, project costing, mole balances, mass balances, report writing, and finally, creating a display and giving a marketing talk. These skills are taught in the context of the design problem.

There is one combined two-hour lecture each week, fol-

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lowed by two official hours of lab with sections of fifteen students. Teaching assistants (TAs) grade lab books and supervise labs late in the semester when the pilot plants are well defined. Laboratories are held open on nights and weekends for four weeks prior to E-Days so that students can have a place to build their prototype pilot plants. Because the students work so many hours prior to E-Days, held in late April, they are not given exams and are released two weeks early in the semester. The course schedule in shown in Table 1.

For the past three years, the design problems have been separation problems that cannot be solved trivially. They were designed to be like a Disneyland ride: molecules blown up to the scale where they can be seen and measured (counted, if possible). This helps the students to visualize mass and mole balances for their sophomore year. In the first year, the students were given candy, gum, and foam spheres. In the second year, they were given iron, zinc, sawdust, salt, and glass beads. In 1994, they were given plastic, glass, and polymer beads, in addition to metal shot. Throughout this article, these various materials will be referred to as beads. In every case the particle size distribution of the beads were nearly identical. Filtering is not allowed to be the sole design solution.

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TABLE 1
Lecture/Lab Topics: Spring 1994

Jan 17-22	Course purpose Course outline-syllabus Grading Rules for notebooks/Grading notebooks Personality styles; Social interaction styles and strengths: Teamwork Form lab groups Assign the semester project Planning laboratory Keeping a time log on project
Jan 24-28	Taking measurements: multiple samples, std, error analysis Measuring physical properties of materials (teach micrometers, soil sieves, balances, etc.)
Feb 1-5	Science vs engineering; degrees/selecting a process Continuation of physical property measurements
Feb 8-12	Using Quattro Pro/plotting packages to present data Lab in computer facility
Feb 15-19	Separation technology/the design process (text) Begin building first prototypes
Feb 22-26	Time management Continue on prototype build
Mar 1-5	Engineering drawing/classroom examples Finalize first prototype and draw views on computer
Mar 8-12	Product testing and evaluation/failure paretos and mean time to failure Test prototype I
Mar 22-26	Project costing/rebuild for cost reduction Plan and build prototype II
Mar 29-	Project planning/create critical path method plot through end of project Build prototype II
April 5-	Mole and mass balances/visual distillation Testing mole and mass streams, distribution coefficients
April 12-	Marketing the product: visual, verbal communication Creating visuals for E-Days Create talk for E-Days
Apr 19-	Write report
Apr 22-23	Engineering Days

Initially, the class is introduced to the social type profiles used by several companies.[3] Through the use of self-administered worksheets, students identify themselves and each other as amiable, driver, analytical, or expressive. The assets of each social style are taught and then teams of three are made by combining students with different social styles. Because studies have shown that women and minorities routinely lose self-esteem when they are the minority members of a team, they are grouped to be the majority of their team.[4-6] For example, a team might be two women and one man, or three women. The teams draw on the strengths of each social style as they progress through their design experience. Three makes a good team size because no one sits idle.

The students keep a corporate quality team lab book with carbon copies that are turned in at the end of each lab session. Every action on the team is documented in the form of a lab write-up, with a purpose, equipment description, procedure, results, discussion, and conclusion. Lab books are written in ink, and all team signatures, as well as the date, are required on every page in order to protect the team's patent rights. The lab books are graded on neatness, format, effort, and thought.

When the students meet in the first lab, they are given pure samples of the beads they will have to separate and are asked to develop labs to quantify the physical properties. They are not told what or how to quantify. They think up as many tests as possible and consult with the instructor or TA about how to use the tools in the lab. The teams meet in a soil's laboratory stocked with balances, micrometers, graduated cylinders, sinks, outlets, tools, yardsticks, sieve sets, drying ovens, and other standard equipment. The instructor supplements with tape, staples, cardboard, cans, fabric, velcro, magnets, and extraneous items that might be useful to a creative mind.

For two weeks the students measure, record, and run statistical studies on the physical properties of the beads. They use computers to plot particle size, weight, density, bounce, roll, and any other distributions they may have measured. Each student calculates a mean value and the standard deviation for each property for each bead type. This is the time when the class is taught to use the correct number of significant digits and to estimate errors.

The students are encouraged to become unbounded in their creativity. For example, some students measure the rate at which each of the beads rolls through velcro when held at different angles. Others measure the distance each bead deviates from its path of travel when a hair dryer is used to blow perpendicular to the roll path. There are an endless number of properties to be measured. The students then make a pareto* of physical properties that shows the greatest variation from bead to bead. They realize that this pareto is unique to pairs of beads and that different properties can be used in series to separate one bead type from the mixture.

After identifying the physical properties that can form the basis of a separation, the teams are asked to brainstorm a series of unit operations that can be linked together to make a separation pilot plant. The rules are that the design must accommodate between 0.5 and 1.0 liter of batch feed. There can be no human judgement involved in the separation. Human power is allowed if it is blindfolded. Pilot plants are rewarded for simplicity of design, structural integrity, speed of separation, manufacturability, quality of separation, minimized cost (floor space, labor, utilities, materials, etc.), independence of human involvement, continuous flow capability, and ease of use.

The students spend several more weeks in the lab designing and drawing views of their proposed plant. The lectures at this time are focused on engineering drawing. The teams are required to submit top, side, and front views of their proposed pilot plant. They gather materials from dumpsters, dorm rooms, home, and other free sources to build their separation pilot plant. Because we do not have the time or money to teach the students to work with metal and wood in a machine shop, they are left with tape, cans, staples, and other less durable materials. Durability becomes a relative concept—the pilot plant only has to hold together through Engineering Days. Students with previous shop skills are allowed to use the shop at CSU's research center, but pilot plants welded from metal do not receive higher scores than those made from cans and tape, if both meet all other criteria equally.

The students have two weeks to build their first prototype separation pilot plants. This is a time of maximum frustration as they realize that going from plans on paper to product in bins is not so easy. It does not take long for reality to set in. Peer relationships change and new respect is found for those creative hands-on students who may not excel on exams—honor students sometimes struggle to control cardboard in a 3-D world. Competition between teams causes the students to work hard, in and out of class, to have the first working prototype pilot plant.

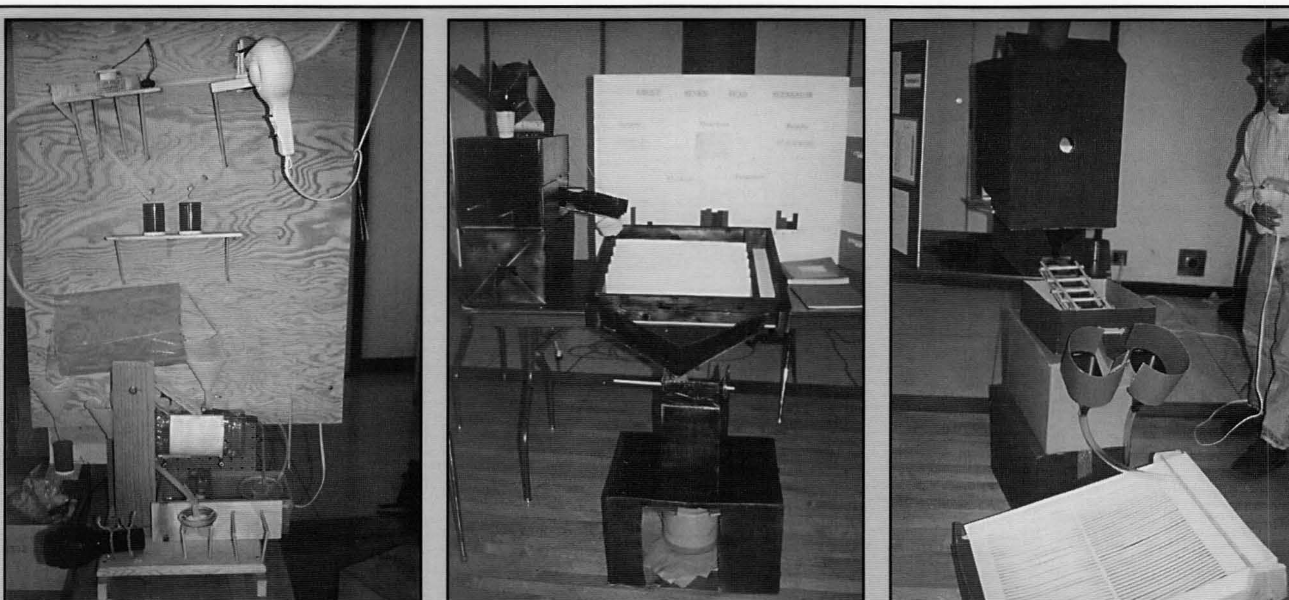
When the prototype pilot plant meets the mass balance goals of 95% total recovery and 50% enrichment in each unit operation, the students are asked to develop a simple statistically designed experiment to test the separation capability over a range of compositions.[8] They typically test a grid of inlet stream compositions and count beads to determine the composition in each "out" bin. The unit operations within the pilot plant are drawn as a series of black boxes. The students write in the exit stream compositions on this diagram and then calculate the mass and mole balances on each black box and on the pilot plant as a whole. They are required to develop a pareto of failure modes (from most to least frequent). Examples of failure modes include: candy in the gum bin, jamming in inlet funnel, or beads flying out of the pilot plant. The team outlines a strategy for understanding and solving each of the failure modes, in order of importance. Here they learn to spend effort where there will be the greatest payoff.

One lab requires the teams to disassemble their pilot plants, down to each piece of tape, in order to complete a costing of the prototype. Sometimes this means weighing gobs of tape and converting this to feet, knowing the mass per length. They go to the library or to stores to find a cost value for each element of the pilot plant and use spreadsheets to cost out the project. The spreadsheet lists the elements in the pilot plant, designer time, and any time that could have been charged to a technician, such as routine testing. Each item is given a unit value in one column, the amount used in another column, and the associated cost in a third column. The expenses are summed, overhead is included, and the students discover that over 99% of the project cost is in engineering time. It is a real "light bulb" experience to learn that their $30 pilot plant actually costs over $5,000 when engineering time is considered. As one student stated, "Now I know why my sunglasses cost so much."

Credit is given in proportion to the success of the team in implementing a cost reduction, a rebuild of the first prototype pilot plant. When they realize that the most leverage in cost reduction comes from saving engineering time, they are ready to learn about time management and the critical path method of project management.[9] Each team is required to develop a pert chart for their project for the remainder of the semester, through E-Days. They are asked to find ways to reduce the schedule and to work in parallel.

After the second prototype pilot plant is complete, more mass balances are performed for a range of inlet compositions. The students are asked to cost out this second pilot plant. They are then given dollar values for the pure elements and asked to calculate a profit for each inlet composition, based on a measured processing rate. For simplicity's sake,

** The pareto is a bar graph of % difference versus physical property, from greatest to smallest.*[7]



Three very individual and unique solutions to the same separation problem.

the feed is assumed to have no cost. A more appropriate model would be to give the students product values based on the purity of the streams.

The students are asked to think of their pilot plants as a series of unit operations, each tailored to enrich one species. They imagine their mixture as a liquid and the "out" bin for that operation as a vapor. Equilibrium is assumed in each unit and distribution coefficients are calculated as a function of composition.

For E-Days, the teams are required to have a typed professional report with an abstract, an introduction, the procedure, the results, and a conclusion. All drawings and spreadsheets, developed over the course of the semester, are included in the appendix. Reports are 15-25 typed pages in length. A display is made with poster board, and a marketing talk is written. All lab books are displayed with the final version of the separation pilot plant. In many cases this is the second prototype, cleaned up and painted. Judges are brought to CSU from Hewlett Packard, Kodak, NCR, Woodward Governor, and other local companies to judge and score all projects in the college. For the last three years, this class has won the freshman E-Days award, finally beating the mechanical engineers.

GRADING

Grading team projects is always difficult. For the first two years, each student was required to keep his/her own lab book, and exams were given. While this made grading easy, with 70% of the grade being earned individually, it created far too high a workload for the students and graders. Now, each team keeps one lab book, with a different person accepting responsibility each week. Students earn individual grades for each week they are the scribe. In-class computer projects, exercises, and quizzes are also graded individually. The TAs take attendance and record observations on individual effort during each lab. The students fill out evaluations of each other's performance at the end of the course. Under this system, 40% of the grade is earned individually through homework, lab write-ups, quizzes, attendance, and peer evaluation. The project, display, written report, and marketing talk contribute to 60% of each grade. Generally, team members receive grades within a letter of each other. When this is not the case, it is because one member clearly ignores his or her responsibilities and simply does not show up in class much of the time.

DISCUSSION

It is interesting that even with the three sphere problem and forty students, no two pilot plants were at all alike, as can be seen in the photographs on the preceding page. E-Days is a perfect demonstration of the value of diversity, as all of the different populations incorporate vastly different tools into their solutions. These range from cross-stitch fabric and blow dryers to power drills. The open-ended problem also allows cross-cultural education. Male students, who have never been in fabric stores, are out looking for lace of different mesh sizes, and women students snoop around the machine shop. One woman probed her kitchen and showed her male colleagues how Karo syrup and corn oil separate candy and gum spheres.

The class of 60-85 students is either team taught with two faculty members or split into two sections. With one common two-hour lecture and four to six two-hour labs a week, each faculty member is responsible for 5-7 contact hours per week. During the month before E-Days, the lab is often held open an extra fifteen hours a week. Fortunately, by this time in the project, TAs are more than capable of sharing the

TABLE 2
Results of Course-Evaluation Questionnaire

	Very True	Mostly True	Rarely True	Never True	Not Appropriate
1. I am more active in class time in this class than in other classes.	12	28	11	4	0
2. I feel better about my participation in this class than in other classes.	11	32	8	4	0
3. I feel better about my accomplishments in this class than in the programming class.	20	23	3	4	5
4. I learn from group members.	24	23	7	1	0
6. I consider the design problem open-ended with no known answer.	14	22	14	5	0
7. I am challenged to think of a solution to this problem.	40	14	1	0	0
8. This class requires me to be creative.	40	14	1	0	0
9. I feel there is no textbook solution to this problem.	34	13	8	0	0
10. I feel my team members are pulling their weight on this probject.	28	19	4	3	1
11. I would rather learn through active discovery than listen to lectures.	37	18	0	0	0
12. This represents real-world problems in the difficulty and unknown involved.	21	23	9	2	0
15. I would come to extra tutoring sessions to learn Quattro Pro.	9	19	19	7	1
17. I know Word Perfect from high school.	27	7	8	12	1
18. I know more about social styles than I used to.	5	30	16	3	1
19. I can recognize different social styles in people now.	12	30	9	2	2
20. I sit around and do less in this class than in a lecture class.	6	13	24	12	0
21. I feel worse about my performance in this class than in the programming class.	5	13	14	17	6
22. My group members do not contribute to my efforts in solving this problem.	1	12	13	29	0
23. The design problem is too easy	0	1	26	28	0
24. The design problem should have an answer that the professor posts.	0	3	14	38	0
25. I expect the professor to tell me everything I need to know and do for this class.	7	13	18	17	0
26. I feel totally defeated by the difficulty of the design problem.	1	17	26	11	0
27. I enjoy coming to the lecture part of class.	1	24	19	11	0
28. I enjoy coming to the lab.	17	32	4	2	0
29. I would learn more by having guest speakers than lectures from the book.	20	26	8	1	0
30. I know I can use the Professor as a consultant on my design project.	20	30	5	0	0

supervision of the teams and ensuring safety in the lab. For the design class to be taught in this time-consuming manner, there has to be a strong commitment by the department head to the value of personal and open-ended education. Because it has been shown that women and minorities are positively influenced by increased interpersonal interaction with faculty,[11,12] this type of course is a superb tool for increasing the retention of these students.

The class is very successful in meeting its goals. A summarized course evaluation is shown in Table 2. While it is time-consuming for both the instructor and the students, all come away with feelings of pride and accomplishment. The students certainly develop a strong sense of camaraderie and close ties to the faculty members. It is not unusual for "D" students to become motivated by doing something "real" and to earn an "A" grade in the process. All students learn teamwork and an appreciation for personality types and work styles other than their own. They learn that there are many solutions to any given problem and the goal of engineering is more than the manipulation of equations. Best of all, they learn that solving problems and building "real things" can have a contagious excitement.

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