A Freshman Design Experience: MULTIDISCIPLINARY DESIGN OF A POTABLE WATER TREATMENT PLANT

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To succeed in the current technological environment, engineers need theoretical as well as practical knowledge. It is essential that a part of their education be comprised of hands-on practical training that prepares them for the challenges that they are expected to encounter in professional practice. This will serve to reinforce the students' interest in engineering and open their minds to the numerous exciting challenges that lie ahead of them. Moreover, students who participate in undergraduate research/design are more likely to pursue graduate studies.[1]

While the current engineering curricula in most schools build a strong understanding of theoretical concepts, in implementation of these concepts many fail to provide design and hands-on experiences in a multidisciplinary environment. (Herein, multidisciplinary is defined as a course that requires the fundamental aspects from chemical, environmental, civil, mechanical, and computer engineering.)

Many high school students choose to pursue engineering in college because of their desire to apply cutting-edge scientific knowledge to solve practical problems. During the first two years in most engineering curricula, however, the students rarely have the opportunity to employ their newly gained knowledge and understanding toward innovation and design. This renders the engineering disciplines less attractive and as a result, many of the students become disillusioned and choose to pursue another field of study. This is one cause of low retention rates in most engineering disciplines. Our internal departmental surveys show that students believe that deductive classroom learning is more effective if a design class — which exposes the student to real-life engineering applications — precedes it. An ideal freshman design class must lay the foundation for future learning by teaching some fundamental theory, and it must utilize this theory to design and fabricate a real-life engineering system.

This design experience must also help the students put the future classroom-based learning in perspective. Indeed, if freshmen are exposed to team problem-based learning early, it is more likely that they will achieve success in subsequent years.[2] In addition, when freshmen are exposed to hands-on learning, the result is an increased ability to apply the lessons learned in future classes.[3]

This project aimed to determine the success of freshman multidisciplinary design to help retain students in the engineering disciplines at the University of Florida (UF). To overcome the deficiencies in the engineering curricula described above, we have attempted to incorporate interdisciplinary design and problem-based learning into the freshman-level engineering curriculum.

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To maximize hands-on learning, we offered a full-scale project that required designing, fabricating, and operating a pilot-scale water treatment system. Of the several methodologies investigated, Burton and White found the full-scale project most successful for creating an exciting environment, best for introducing the design concepts and engineering tools, and best for promoting teamwork.[4]

MULTIDISCIPLINARY COURSE DESCRIPTION

Prior to the development of this multidisciplinary freshmen design course, the College of Engineering at UF already offered a course titled "Introduction to Engineering" (EGN 1002) that introduces freshmen students to all 11 engineering disciplines available at UF. Its intent is to help the students make a more informed choice while deciding their majors. Each department uses different techniques to kindle the students' interest in the three hours that is allotted to every engineering discipline. The contents vary from a PowerPoint presentation summarizing key aspects, to simple hands-on experiments, to tours of local facilities. The course also aims to keep alive the students' interest in engineering, thereby increasing the retention in the college.

Statistics show that the retention rate among the students who took this course (51%) is higher than the retention rate in a peer group (34%) that is matched to have similar levels of technical competence as gauged by SAT scores and GPA.[5] Thus, this course has clearly been successful in increasing retention, and has exposed the students to some elements of design through simple hands-on experiments. The three-hour time spent in each department, however, is not enough to provide any substantial design experience to these students. Therefore, we decided to build upon this success and further strengthen the introductory course by adding to it a multidisciplinary design component. The result was an experimental EGN 1002 course offered over three semesters in 2001 and 2002.

Funding for the project was through the National Science Foundation-sponsored program, SUCCEED (Southeastern University and College Coalition for Engineering Education, NSF Cooperative Agreement No. EID-9109853). This pilot-scale water treatment project imparted knowledge of chemical and environmental engineering for designing the unit operations; mechanical and civil engineering for fabricating the basins, mixers, and impellers; and electrical and computer engineering for designing the optical turbidimeter and providing online data acquisition and control. Thus it provided a multidisciplinary, group-design experience to the students, which is reportedly lacking in current curricula according to the ABET 2000 report.[6] This project aimed to provide freshmen with an opportunity to experience, understand, and apply engineering concepts — and develop problem-solving skills during their first year. The course had four main components: (1) acquire the knowledge base required for the design; (2) fabricate the potable water treatment plant; (3) develop teamwork skills; and (4) use this design project to serve as a base to support future learning and to motivate students to learn more.

This course is targeted to increase the student retention rate in all engineering majors. Accordingly, statistics were compiled on all students, and some results are discussed below, to determine if the course achieved its objective.

Class Lectures

Our teaching philosophy can be simply stated in three words: "Get students involved." We believe teaching is most effective if students are actively engaged in the learning process. Thus, we prepare lectures with ample opportunities for asking questions and interacting with students. The purpose of lectures in this design class is twofold. First, the students are given the knowledge base that is needed to accomplish the design objectives. Second, the link is demonstrated between theoretical concepts and the practical application of these concepts in design. It is extremely important to establish this link early in the students' careers because it helps them put all future classroom learning in perspective. Keeping these objectives in mind, we delivered lectures on the following topics in the class:

(a) ***Group Dynamics and Presentation Skills:*** *This lecture was aimed at improving communication and presentation skills, as well as helping students develop an understanding of the importance of group dynamics both in this course and in their future careers.*

(b) ***Water Chemistry:*** *This lecture covered the concept of reaction equilibrium and its application in the process of hardness removal, precipitation, flocculation, and acid-base reactions. It also discussed the various kinds of impurities present in water and the processes for removing them.*

(c) ***Calculus and Reaction Kinetics:*** *This lecture introduced the basic concepts in calculus and applied them to develop the design equations for batch and well-mixed reactors. The basic reaction mechanisms were also discussed in this lecture.*

(d) ***Design of Unit Operations:*** *This lecture covered the physics and the design equations for designing flocculation, sedimentation, and filtration basins.*

(e) ***Hardware and Software for Data Acquisition:*** *This lecture covered the basics of A-D boards and the use of Labview in writing data acquisition codes.*

Project Evaluation

The students were evaluated on the following:

- ***Teamwork:*** *Their "teaming" skills were gauged based on faculty observation, faculty interviews, and peer evaluations. During the design and construction phases of the pilot plants, the faculty coaches observed and interviewed each member of the team to evaluate participation and understanding. Peer evaluations were completed via a questionnaire that evaluated each team* *member's level of participation, ingenuity/creativeness, and project understanding on a scale of 1 to 5. After the questionnaires were completed, the students could compare their average score to the team's average score to evaluate how the team perceived their personal participation on the project.*

- ***Quality of the final presentation:*** *The final presentation was judged by the course faculty and student assistants. Criteria used in the judging included quality of the PowerPoint slides (e.g., font size, use of pictures), ability of each team member to maintain eye contact with their audience, posture, and quality of speaking (e.g., avoidance of both long pauses and the repetitive use of "uhmmm").*
- ***Success of the design effort:*** *The design project was judged by the same panel on the basis of the effluent turbidity measurement (goal was less than 0.2 turbidity units), color (none), alum consumption (least amount possible), control (proportional control of alum input as a function of turbidity measurements), and the understanding of the technical concepts by the team members.*

Course Implementation

The experimental EGN 1002 was designed to build upon the already established course by letting students choose five engineering disciplines of interest and then taking the students to only these five departments for the three-hour introduction sessions. This allowed students to utilize the remaining 10 three-hour periods to participate in the design experience by fabricating a potable water treatment plant.

During the first session, the experimental course was taught to a group of 34 students chosen randomly from 50 volunteers. Since it was a summer offering, two three-hour periods were available each week. Two hours were devoted to the lecture and four hours to the lab. The lecture hours in this course were used to introduce the problem to the students and provide the knowledge base needed to achieve the design objectives.

The students were randomly split into two groups of 17, and further subdivided into four subgroups of four to five students each. During the laboratory sessions for pilot-plant design, the teams of students employed the design equations learned during the lectures (<http://www.ees.ufl.edu/homepp/mazyck/webpage/egn1002/lectures.htm>) to construct the unit processes (rapid mixing, flocculation, sedimentation, and filtration basins) required for processing approximately 0.25 gal./min. of water (Figure 1). The size of each unit process for the pilot plant was designed based on the relationship between contact time, flowrate, and volume (*i.e.*, volume is equal to the product of flowrate and time). Therefore, since the flowrate was known and the students could choose a residence time for each unit process based on the lecture notes, the volume of each basin could be designed. Sheets of Plexiglas measuring 4 by 8 ft. were provided to construct the unit process basins. The students were required to size the sheets, cut the sheets with a table saw, and cut the holes for baffles and water flow via a drill press. The basins were glued together and seams were sealed with silicone to avoid water leakage. If mixers were chosen (some groups elected to accomplish mixing with baffles only), standard mixers purchased from a laboratory supply company (*e.g.*, Cole-Parmer) were provided. With respect to the filter, the students were required to use gravel, sand, and activated carbon, but the depths of these media were chosen by each group. The water processed was collected from nearby Lake Alice (very high color and moderate turbidity) and cost for each pilot unit was less than $500. (The Web address above includes pictures of the pilot plants as well as lectures and various other course details.)

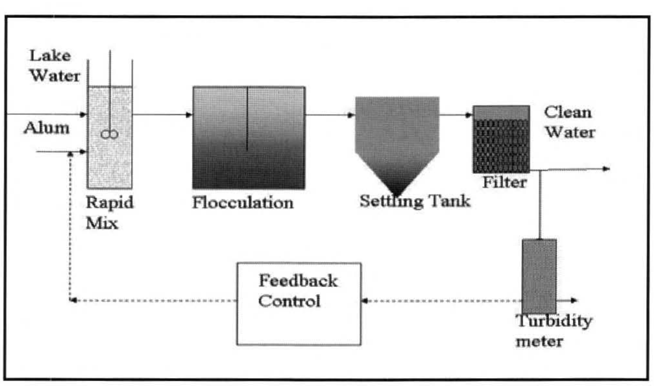

Figure 1. *Potable water treatment pilot-plant schematic.*

It took approximately six hours to design and construct the basins, and another two sessions to assemble the entire water treatment plant. Aliquots of water were withdrawn at the inlet and outlet of the process at fixed intervals of time, and the pH, turbidity, and color were measured. After the construction of the pilot plant, students varied the flow and monitored water

TABLE 1
Results of Selected Questions from Second and Third Course Offerings

Question(s)	Second Offering Average Score	One Standard Deviation	Third Offering Average Score	One Standard Deviation
1	4.4	0.6	4.3	0.4
2	4.1	0.6	4.6	0.5
3	4.0	0.6	4.1	0.4
4	3.1	0.7	3.2	0.5
5	3.3	0.7	3.6	0.4

1. Did the class help to build and demonstrate the importance of teamwork?
2. Was the class a positive learning experience?
3. Were the chemistry lectures successful in relating the theoretical concepts to the design project?
4. Did this class improve your PowerPoint skills?
5. Did the class demonstrate the importance of presentation skills?

quality (*i.e.*, turbidity) and made adjustments to baffles and mixing rates for two weeks. In the final week of class they compiled their data, prepared a brief report, and gave a group presentation. The students also learned the idea of using feedback control to manipulate the alum dosage to keep the effluent water turbidity to within a tolerable limit.

For the second offering, the goal was to improve the course based on an end-of-semester questionnaire (specific results discussed below). The major change implemented for the fall course was to decrease the size of each team. We accepted 36 students into the course and we subdivided them into four teams. Team responsibilities included designing and fabricating the pilot plant and implementing feedback control. The effluent turbidity was measured by a commercial turbidimeter and the digital output was fed to the pump that adds alum to the rapid-mix basin. A proportional control scheme was implemented by using the modules available with the turbidimeter and the pump. This gave the students a basic idea of feedback control. Other changes included streamlining the chemistry and calculus lectures to delineate the connection between the theory and the design more clearly. To help accomplish this, the chemistry lecture was immediately followed by a jar-test experiment where students varied pH and alum dosage to study the impact of these variables on flocculation and sedimentation.

The third offering remained unchanged except that the faculty served as mentors for undergraduates (*i.e.*, the first two authors of this manuscript) who taught the course. As such, we only accepted 11 students so as to not overload the two undergraduate instructors. In addition, three freshmen students from the previous offerings participated in the teaching of the course via lending support to the instructors during the design and construction phases of the course.

COURSE ASSESSMENT

At the conclusion of the first semester, the students completed a simple questionnaire consisting of 14 questions aimed at evaluating the success of this course and helping us determine ways of improving the class.

The results showed that we were very effective in imparting design and presentation skills, and the concept of teamwork (average of 8.3/10), but we were not successful in relating the theoretical concepts in the chemistry and calculus lectures to the design project (average of 4.9/10). All of the students made useful comments. Some considered the "hands-on experience" to be the most valuable component of this course. Many suggested reduction in the size of the teams.

During the second semester, we modified the course, but we also recognized that we needed to improve the survey by (a) improving the phrasing of the questions, (b) increasing the number of questions (from 14 to 24), (c) reducing the rating scale from a total of 10 to 5, (d) including redundant questions, and (e) adding a Likert scale that described the meaning of the scale. For example, 1 indicated strongly disagree, 3 indicated neither agree nor disagree, and rating a question a 5 indicated that the student strongly agreed. Based on the results from this revised questionnaire, the students found the second offering of the course more rewarding as compared to the first offering. Also, the students rated the chemistry lectures much higher than those in the first offering, which could partly be attributed to the more interactive teaching methodology that we adopted in the second offering. Some of the results from the second and third offering are compiled in Table 1.

Overall, each semester the students scored the class with higher marks. We were particularly pleased with the third trial results because two undergraduate students covered the lectures and design labs with minimal faculty supervision. This was done to assess if the course could be effective with undergraduates and graduates running the course with faculty coaches.

Approximately two years after completing the course, we administered an e-mail survey to 13 randomly chosen students to determine their status in the engineering program, their continued motivation for completion of an engineering degree, and the impact of the course on their current engineering studies. Of the respondents, 92% of the students were engineering majors at the time of the class. (EGN 1002 is a course open to the entire student body, and as such, some nonengineering students elect to take the class). At the time of the survey, as the students were entering their upper division studies, 77% remained engineering majors. Students were then asked to rate their experience in the class through a series of four questions. Ratings ranged from 1 to 5, with 1 representing a response of "Not Really" and 5 representing a response of "Very Much." Table 2 displays the results of the questionnaire. Overall, the students expressed that the class was a rewarding ex-

TABLE 2
Student Responses to E-mail Questionnaire Approximately Two Years After the Course

Question*	Average Response Value*	Standard Deviation
Do you feel this class prepared you for your future studies?	3.6	1.0
Do you feel this class motivated you to participate in undergraduate research?	3.6	0.7
Do you feel this class was worth the extra time and effort required to conceptualize and develop the design?	4.3	1.0
Would you recommend this experience to other freshmen?	4.6	0.7

**Note: Questions were rated on a scale of 1 to 5. A rating of "1" represented a response of "Not Really." A rating of "5" represented a response of "Very Much."*

perience for them. Many would recommend the experience to other freshmen. Moreover, the students found that the principles taught in the course were an asset in their future studies, including teamwork, multidisciplinary solutions to engineering problems, and an idea of the practical applications of their studies. Table 3 displays a sampling of the comments received with the questionnaires.

Recently, we calculated the retention rate for this experimental course, and of the 81 students who enrolled, 50 either still remain in engineering or graduated with an engineering degree. Unfortunately, at the time the course was offered, we did not recognize that some students (probably less than five) were not engineering students to begin with, so the overall retention rate is likely even higher than the observed 62%. When comparing this retention rate to the retention rate for the original EGN 1002 course (51%),[5] the multidisciplinary design course showed marked improvement.

When establishing a course of this nature that focuses on a particular theme (*i.e.*, a potable water treatment plant), some may be concerned that only students in chemical, civil, or environmental engineering might be interested or that students in different engineering disciplines might change their major to one more aligned with the experiment. This was not the case, however. Of the 50 students who graduated or are still enrolled in engineering, 15 are/were electrical engineering majors. The remaining 35 students were approximately equally dispersed among civil, chemical, agricultural and biological, mechanical, and computer engineering, while only one student is currently enrolled in industrial and environmental engineering.

CONCLUSIONS

Students successfully built pilot-scale water treatment plants that met the turbidity and color standards, and therefore, this class not only provided a design experience during their first year, but also provided them with new confidence that they could build upon in future classes.

Surveys at the conclusion of each course offering provided positive feedback that this multidisciplinary design course was a positive experience for the students, and the retention of 62% of the students in engineering suggests that implementing this course into the curriculum at the University of Florida is a worthwhile pursuit. Presently, the faculty instructors and associate dean for academic affairs are reviewing the course outcomes and developing an implementation strategy.

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TABLE 3
Additional Comments Received from Students

"Overall, I would recommend the class to an entering freshman. The fact that we got to design and build our own water (treatment plant) seemed overwhelming at times but was a great experience and one that not many freshmen at large colleges get to experience."
"As I've taken more classes I have recognized some of the principles that we discussed in lecture."
"I would recommend the experience to freshmen because it gives them an idea of what the industry is like in the real world with other disciplines involved."
"This project gave me great experience for getting a job at (the Florida Department of Environmental Protection). However, I think the experience from the project prepared me for any sort of job situation where teamwork and problem solving is involved, not just in the environmental field."
"I really enjoyed the class and think that this is a great program. It combined multiple disciplines and implemented teamwork skills."
"The hands-on training and teamwork skills developed in this class are incredibly valuable no matter what engineering field you go into. You get a lot more out of it than you realize right away. Thanks for all the help!"
"I believe that this experience was one which allowed me to view engineering in a different light and start to examine the practical applications, which all my hard work in academics were for."
"Engineering classes can get discouraging because all you learn is theories, formulas, and how to solve simple problems. However, as a practicing engineer, you deal with designing a multitude of things and you are constantly dealing with people. This class was able to show freshmen engineering students how to design and work in a group of a variety of different engineers, which is common in the engineering world."

Learning Through Simulation

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Finding 3. The points identified as key for effective engagement with the simulation in order to facilitate learning were generally supported by our results.

- *A notable exception to this is an open-ended task structure, which appeared to hinder learning in this study. By eliminating the open-ended structure during the interviews, students' conceptual understanding was deepened. Open-endedness should be retained to encourage system exploration, but sufficient "hints" or guidelines must exist to ensure desired concepts are focused on.*
- *Briefly sensitizing students for learning through simulations was not successful in changing their tutorial-like view of simulations.*
- *A physical learning history is a poor substitute for the ability to stop, rewind, or restart a simulation.*
- *External factors that students bring into the simulation environment with them can hinder engagement, thus undermining their experience. Major hindrances include mood, previous experiences, and the context in which students perceive the exercise. This implies that the "ideal" environment can be subverted by external factors.*

Finding 4. The majority of the students see simulations merely as sophisticated calculators that save time.

- *Simulations are viewed as tutorials that need to be completed quickly and accurately, not as potential learning exercises.*
- *Students' mindsets regarding simulations need to be developed.*

This may be addressed in several ways

- *Structure tasks to elicit conceptual rather than numerical answers.*
- *Remove the assessment weighting of such tasks in the course structure.*
- *Begin sensitizing students to the benefits of simulation learning before any simulation packages are introduced in the degree.*

Finding 5. Allowing the students to use their class notes while completing tests and simulation tasks may eliminate a guessing approach.

Students in this study identified consolidation as an essential part of their learning. The use of the following should be encouraged:

- *Class notes*
- *Summarizing or another form of consolidation*

This will also ensure that students retain any new understanding and bring their prior theoretical understanding to bear when performing the simulation.

This study suggests important implications for the design of simulation exercises for learning. The features identified as facilitating engagement with simulations are insufficient due to external factors that have an impact on the learning context as well as students' preconceived perceptions of simulations. Simulations need to be introduced as learning tools from early in the program, before students begin working with them. Enjoyment is vitally important for student engagement with simulations. Finally, simulation tasks must encourage exploration, but also provide sufficient guidance to help students focus on the key variables necessary for conceptual understanding.

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