AN INTERDISCIPLINARY COLLABORATIVE APPROACH IN TEACHING FRESHMAN ENGINEERING DESIGN

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Abstract---*In the early 1990's, with the advent of the National Science Foundation Coalitions, the engineering curriculum began to change to introduce engineering design concepts early in the education process rather than waiting for the senior capstone courses. The initial courses were disciplinary in nature but in 1996 interdisciplinary courses were introduced.*

At NJIT educational and research collaborative efforts between Civil and Chemical Engineering Faculty have been common practice. Hence, four modules were developed based on environmentally related industrial or municipal design problems. In each of these modules, the Civil Engineers had the responsibility for the siting factors, which were both environmental and political restrictions, and the economic aspects of the problem. The Chemical Engineers had the process analysis and design responsibility. Teamed in groups of three to five, students were introduced to a real, open-ended design problem and the concepts of siting, process analysis, process design, teamwork and oral and written communications.

Index Terms--- *Chemical, Civil, Environmental Engineering, Freshman Design, Interdisciplinary, NSF Coalitions*

INTRODUCTION

In the early 1990's, with the advent of the National Science Foundation Coalitions, the engineering curriculum began to change to address the need of introducing engineering design concepts early in the education process rather than waiting for the senior capstone courses. The effort was in response to concerns expressed by faculty, industry, administrations, and student demands. Our industrial colleagues kept requesting graduates with better training in communication and teamwork skills. Administrations were concerned about engineering student enrollments, retention and curriculum modernization. Students were requesting exposure to their field of interest earlier in their studies and faculty began to see the need requested by industry, administrators and the students. New Jersey Institute of Technology (NJIT) became part of the Gateway Coalition and in 1992, began the development of a Fundamentals of Engineering Design program in the freshmen year. With the advent of the National Science Foundation Coalitions such as Excel, Foundation, Gateway and Succeed to name a few, many freshman engineering design courses were introduced to expose students to open-ended, design concepts early in their studies. Most of the programs, however, focused on disciplinary modules. Regan and Minderman [1], Gramoll [2], Cain [3], Hanesian and Perna [4], Keilson [5] and Traver [6] have discussed examples of these disciplinary modules. This approach of developing a specific project to introduce design to freshmen is typical of the programs across the country. The literature reported at conferences, especially the ASEE Annual Conference Proceedings, ASEE regional conferences, and the ASEE/IEEE Frontiers in Education Conferences, all have differences in the approach to introducing freshmen to design but most of the literature discusses disciplinary design modules. A few examples of interdisciplinary design courses are by Calkins, Plumb, Chou, Hawkins, and Coney [7], Hesketh, Slater and Gould [8], and Ramachandran, Slater and Schmalzel, [9]. However, the common theme in all discussions and approaches at various universities, for disciplinary or interdisciplinary courses, is " hands-on" experience, team effort, improving oral and written communication skills, an approach to solving open-ended problems, critical thinking, "real world" problems, and application of computer techniques to the solution of engineering problems very early in the Freshman year.

The initial NJIT courses were disciplinary in nature but in 1996 an experimental program was started to introduce interdisciplinary courses.

INTERDISCIPLINARY COURSE DEVELOPMENT

Beginning in the Spring of 1996, interdisciplinary teaching teams and courses were established between Biomedical and Electrical Engineering, Industrial and Mechanical Engineering and Civil and Chemical Engineering. The Biomedical and Electrical Engineering Faculty developed a project on an Electrocardiograph Device and Prep-check. The electrical and Mechanical Engineering Faculty cooperated on two projects, a Floppy Disk Drive of the

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Computer and a Heat Sink of the CPU Fan. The Industrial and Manufacturing Engineering Faculty and the Mechanical Engineering Faculty developed the lawn Sprinkler and StepLadder Projects. The faculty of Civil and Environmental Engineering (2) and Chemical Engineering (2) developed four interdisciplinary courses. These courses were coupled with Humanities and Computer Aided Design/Graphics components. The courses were for fourteen weeks per semester, two hours and ten minutes per week with a two hour and ten minute CAD/Graphics and software applications class. The Humanities component met three hours per week for the semester. At NJIT, for a long time, educational and research collaborative efforts between faculty from the departments of Civil and Environmental Engineering and Chemical Engineering, Chemistry and Environmental Science have been common practice. In the research area, this collaboration has led to the founding of the internationally known Hazardous Substance Management Research Center and a new undergraduate Environmental Engineering Program to augment and support the existing MS and Ph.D. programs. Therefore, when change occurred in the freshman year in order to introduce the concept of "engineering up front" through a interdisciplinary freshman engineering design course, it was only natural for faculty from these departments to collaborate in developing such interdisciplinary courses. The common area four an interdisciplinary design experience was with a focus on the environment. Four modules were developed based on an environmental related industrial or municipal design problem. The four were:

- The Siting of a Municipal Landfill in a Residential Community
- The Siting and Process Design of a Municipal Wastewater Facility
- The Siting, Process Analysis and Design of a Manufacturing Facility Using Hazardous Materials in a Residential Community (The Manufacture of Aspirin)
- The Siting of a Roadway Through a Residential Community and the Minimization of Air Pollution

In each of these modules, the Civil Engineering Faculty had the overall responsibility for the key facility siting factors, which were environmental restrictions, political restrictions, and the economic aspects of the problem. The Chemical Engineering Faculty had the process analysis and design responsibility. Students were responsible for the final site selection, environmental impact analysis and the process and plant design. Students teamed in groups of three and wrote a final report on the solution of the problem and also presented their results orally. The end result was that the students were introduced to a real, open-ended design problem and the concepts of siting, process analysis, process design, teamwork and oral and written communications.

THE SITING OF A MUNICIPAL LANDFILL IN A RESIDENTIAL COMMUNITY

In the Spring of 1996, "The Siting of a Municipal Landfill in a Residential Community" was developed [10]. There were 12 students in the class, who worked in teams of four each. The design problem was to site a municipal landfill for a community, consisting of 45,000 households of typical average size (three people per household). The design criteria provided were twenty (20) pounds per day of refuse generated for each household, a landfill life of twenty (20) years with maximum lift height of twenty (20) feet, using compactor trucks of 28,000 pounds capacity and with two (2) pickups per week. Site visitations were made to the Gloucester County Landfill, Hackensack Meadowlands landfill and the Development Commission Landfill. Site analysis was to be done for both no recycle and recycle scenarios. Using a United States Geological Survey (USGS) quadrangle map, each team of students was required to investigate three to five potential sites of their choosing. From these sites, they had to select the best site, investigate the cost of site development and consider the environmental, political and social restrictions. The culmination of the course was a written team report detailing their considerations and recommendations to address the design problem followed by an oral presentation to their classmates and the faculty.

THE SITING AND PROCESS DESIGN OF A MUNICIPAL WASTEWATER FACILITY

This module focused on the siting and process design of a municipal wastewater facility [11, 12]. There were 18 students in the course. The Civil and Environmental Engineering Faculty guided the students, divided into groups of four, through the siting considerations of the design while the Chemical Engineering Faculty focused on the process design considerations and the process cost estimation. The facility was to serve 45,000 households with an average of three people per household, and a per capita water consumption of 80 gallons per day. The plant was to be located between the south branch of the Raritan River and Highway 202 in the Township of Branchburg, New Jersey. The influent stream had a BOD_5 if 250 mg/L and suspended solids of 250mg/L, while the effluent stream could not exceed a BOD_5 of 30 mg/L and suspended solids of 30 mg/L. As part of the course, the students were taken on a field trip to the Passaic Valley Sewerage Commissioners wastewater treatment facility in Newark, New Jersey. This facility serves a 100 square mile area in Northern New Jersey and has a capacity of 330 million gallons per day. It services 36 municipalities with a population of 1.3 million and discharges the treated effluent into New York Harbor. This 156 acre plant is the largest wastewater treatment facility in the Eastern United States and processes about one fourth of the wastewater generated in New Jersey.

With this background the students were given a simplified process flow sheet and told to site and design the facility. The Civil and Environmental Faculty worked with the student groups on:

- Siting considerations (zoning, soil)
- Field reconnaissance trips to the proposed site area (photos)
- Environmental restrictions and regulations on the sites
- Political constraints on the sites (historical value, "not in my backyard" problem, etc.)

Economic aspects of the proposed sites (property values)

- Site evaluation and selection

The Chemical Engineering Faculty guided the students on the process design aspects of the facility based on Sundstrom's [13] textbook. The analysis included:

- Process flow sheets of the primary and secondary treatment
- Definitions used in the design of wastewater treatment
- Discussion of the simplified flow sheet
- Material balances for the process units
  - Flow rates
  - Composition of streams
  - Size and the number of the process units needed
- Plant cost analysis
  - Plant construction cost
  - Annual operating and maintenance cost

The students were encouraged to seek help from local government agencies and after careful consideration of all factors; the student groups located three to five potential sites and made a final recommendation based upon all of the factors cited. Two of the four groups picked identical sites while the other two groups picked different sites.

Simultaneously, the students performed the necessary material balance calculations, determined the size and number of process units and performed the process cost analysis. Students relied on Sundstrom and Klei [13] for the process calculations, Kawamura [14] and the Engineering News Record Index for process cost analysis and inflationary effects, and the Water Environment Federation, American Society of Civil Engineers (ASCE) for equipment size determination [15].

The student's results varied for the wastewater process design. The plant cost estimates for the four groups ranged from $ 6.0 to $ 7.6 million. Operating and Maintenance costs ranged from $ 450,000 to $ 500,000 per year and the facility size was about 30 to 35 acres. Overall the students felt that the project required to much work for the credits given, but they enjoyed the effort, especially the team approach to the problem and the very close student-faculty interaction that was needed to solve this problem. Based on the experiences in teaching this course, a workbook [12] was developed to aid the students perform the complex material balances, which normally are taught to Chemical Engineering students in the sophomore year.

THE SITING, PROCESS ANALYSIS AND DESIGN OF A MANUFACTURING FACILITY USING HAZARDOUS MATERIALS IN A RESIDENTIAL COMMUNITY (THE MANUFACTURE OF ASPIRIN)

In the Spring of 1997, the Civil and Environmental and Chemical Engineering Faculties developed a meaningful, interdisciplinary course with an environmental approach, the design and siting of a hazardous substance manufacturing facility in a residential community based on the production of aspirin [16, 17]. The interdisciplinary team gave five lectures on an introduction to the course, the siting of the facility, the aspirin manufacturing industry, soil conditions, cost estimation and finally effective written and oral communication. The 20 students were divided into groups of five each.

Various health hazards were discussed by the Civil and Environmental Engineering Faculty and the Toxic Substances Control Act of 1976, Resources Conservation Recovery Act (RCRA), Emergency Planning and Community Right to Know Act of 1986, Hazardous Materials Transportation Act (HMTA) of 1975 were presented to the students for background information. Definitions of hazardous waste, F waste (hazardous waste from a non-specific source), K waste (hazardous waste from a specific source), and U/P waste (commercial chemical product) were discussed. In addition, planning, project feasibility, funding, and the usual site determination considerations previously discussed were reviewed. The students were encouraged to visit the sites of the planned facility in Somerset County, New Jersey and speak to government officials. The students again determined three possible sites and recommended the best site. Two of the groups picked sites in Hillsborough, New Jersey near Route 206 and two groups picked sites near the Hunterdon County and Somerset County boundary near Route 202.

The Chemical Engineering Faculty took the students on a field trip to the Hoffman-LaRoche Pharmaceutical plant in Nutley, New Jersey to gain a visual knowledge of a chemical manufacturing facility. The students were given an introduction to the problem, presented the history of aspirin manufacture and were shown a background film. The manufacture of aspirin was from a two step process to make Salicylic Acid from Phenol and Acetyl Salicylic Acid using Acetic Anhydride based on the Kolbe-Schmitt synthesis process.

The students were asked to determine the growth of U.S. population, growth of U.S. Aspirin production, make an estimate of the aspirin needed in the year of 2007AD, estimate the market share that can be captured and hence, determine the design production capacity of the plant. Students were asked to identify all health hazards from the chemicals used in the process using the Material Safety Data Sheets available on the Computer. Mass balance calculations were made to determine the quantities of all products and

by-products formed and of all raw materials required assuming a 100 per cent conversion and a 95 per cent yield in each step of the process Waste streams were specified along with suggested disposal methods. Finally, they were guided into the concepts of pollution prevention in chemical process design. Their results were presented in both written and oral reports. The reports included the background, history, hazardous materials, health, environmental, political, economic restrictions, site evaluations and final site recommendations. Also included were the chemistry of aspirin manufacture using the Kolbe-Schmitt synthesis, process flow sheets, block diagrams, material balances, U. S. population growth, U. S. aspirin production growth, estimate of aspirin needs in the year 2007 AD, estimate of plant production capacity, stream specifications, waste disposal methods, and pollution prevention recommendations.

The students enjoyed working on the project and disliked making an oral presentation. However, their oral presentations were excellent. The written report required a great deal of effort by both the students and the faculty. The initial offering of the course led to the development of a workbook [17] to guide the students through the project calculations. They felt that they gained a good insight into the real engineering profession.

THE SITING OF A ROADWAY THROUGH A RESIDENTIAL COMMUNITY AND THE MINIMIZATION OF AIR POLLUTION

In the Spring of 1997, a fourteen-week course was developed to study the siting of a roadway through a residential community with the minimization of air pollution from carbon monoxide. This class met for two hours and fifty-five minutes and involved nineteen students who were divided into groups of four or five. Student teams were presented with the problem of developing a four-lane expressway, two lanes in each direction, to connect two major highways. The connecting highway was to be located between Highway 22 and Highway 202 at the Hunterdon County and Somerset County boundary in Branchburg, New Jersey. The actual highway route was to be selected based upon consideration of land cost, social, political, and environmental impacts. Each group was assigned a different peak hour vehicle rate, which ranged from 1200 to 2000 vehicles per hour. The speeds that had to be maintained were 55 miles per hour maximum on the main highway lanes and 15 miles per hour at the highway ramps. Air pollution levels (i.e. carbon monoxide concentration levels) were determined by using the software program, CAL3QHC [XX], which allows calculation of carbon monoxide and particulate matter from auto exhausts within the proximity of the roadway.

In each study, a USGS quadrangle map, soil information (prepared by the Soil Conservation Service, US Department of Agriculture), and other information regarding site selection criteria, engineering cost figures and projected highway traffic volumes were provided to each group. The Civil and Environmental Engineering Faculty worked very closely with the students on these aspects of the problem. In addition, they discussed the NEPA (National Environmental Policy Act), and the contents associated with environmental impact statements as developed under the NEPA Act. The faculty showed the students how to use the software, CAL3QHC and Mobile 5a, which was made available through the United States Environmental Protection Agency.

The Chemical Engineering Faculty worked closely with the students on the air pollution aspects of the problem. They discussed the history of air pollution and the diesel engines and gasoline engines used in automobiles and other vehicles. The historic factors and the resulting major legislation were also discussed. Information on the chemistry of combustion and photochemical smog was presented. Dispersion aspects of the problem caused by wind, turbulence, lapse rates and atmosphere stability, and topography were discussed. Finally, material on health problems caused by specific air pollutants and the Ambient Air Quality Standards for these pollutants was presented.

The students developed a profile of carbon monoxide and particulate generation associate with the highway traffic as a function of average speed, varying traffic flow rates, different times, varying wind speeds, and directions, varying distances from the receptors to the highway, varying atmospheric mixing heights and varying ambient temperature conditions. The intent of this analysis was to allow the students to appreciate that the analysis of present and projected air quality impacts on a particular area of study id a dynamic process and an open-ended problem depending upon the variables used. The student groups isolated possible sites and finally chose one. All of the groups recommended similar but different routes. They presented their results in a comprehensive written report and made an oral presentation to the faculty and students in the class.

CONCLUSIONS

In all of these four modules, the students

- were impressed with the course
- enjoyed the experience
- enjoyed the team effort

but they complained about “to much work” and objected to being forced to take a course in an area not of their choice.

The faculty enjoyed the challenge of taking a complex problem and simplifying it for comprehension by freshmen. They also enjoyed working with students whom they may never teach again, but having the students constantly seeking them out for advice in the upper class years. One important lesson was learned by the faculty and that is that student reaction to the courses is very highly related to the instructor. Only the best instructors in a

department should be assigned to these Freshman Engineering Design courses to enable a meaningful experience.

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