Paper No. 2004-1177

Multi-disciplinary Capstone Two Course Sequence at the State University of New York at Binghamton

Dr. George D. Catalano
The Watson School of Engineering and Applied Science
State University of New York at Binghamton

Abstract

The mechanical engineering department, and the electrical and computer engineering department at the State University of New York at Binghamton have collaborated to offer a multi-disciplinary senior level, capstone design course. The two-course sequence requires students to demonstrate the ability to apply their formal training in engineering science, design and project-management by executing a real-world project. The projects have been generated both in-house through the sponsorship of a Binghamton University faculty member and externally by an industrial client. Additionally a mechanism was established wherein a team of students developed a project from their own imagination with the requirement that an engineering faculty member serve as the advisor. The course sequence has been offered for the past two years. Data gathered from the offering of the courses as well as assessment of the students' experiences has shed light on both the strengths and weaknesses of the existing engineering program.

Introduction

Each year, more than 100 students receive undergraduate degrees in electrical, computer, systems and industrial and mechanical engineering, the engineering disciplines offered by the Watson School of Engineering and Applied Science at the State University of New York, Binghamton (SUNY-Binghamton). As required by the guidelines set forth in ABET EC2000, students during their senior year must enroll in and successfully complete a capstone design experience. The capstone design experience helps students begin to bridge the gap between their academic and professional careers by exposing them to the technical demands, potential pitfalls, and professional expectations of engineers and researchers.

Previous to the development of the new multi-disciplinary capstone sequence, each engineering department in the Watson School at SUNY-Binghamton offered its own discipline- specific capstone design course. (Figure 1) At the direction of the dean in September 2000, a committee consisting of all department chairs, undergraduate program directors, and the associate dean for administration was established. This committee met regularly over the course of the academic year and recommended that a pilot multi-disciplinary capstone project sequence be developed and offered beginning in fall 2001. The Department of Electrical and Computer Engineering (ECE), and the Department of

Mechanical Engineering (ME) agreed to work together to pilot a joint capstone experience while the Department of Systems and Industrial Engineering decided to maintain their own approach. Separate ECE and ME course listings were maintained while the administration and teaching responsibility of the courses was given to the Division of Engineering Discovery and Design, the organizational unit that also administers the common first two years in engineering at SUNY-Binghamton.

For the new multi-disciplinary capstone course, projects were generated in the following three ways: (a) in-house through the sponsorship of a SUNY-Binghamton faculty member; (b) externally by an industrial client; or (c) by a team of students who develop a project from their own imagination with the only restriction being the requirement of a SUNY-Binghamton engineering faculty member to serve as the technical advisor.

The present work documents the experiences garnered during the first two years of the course.

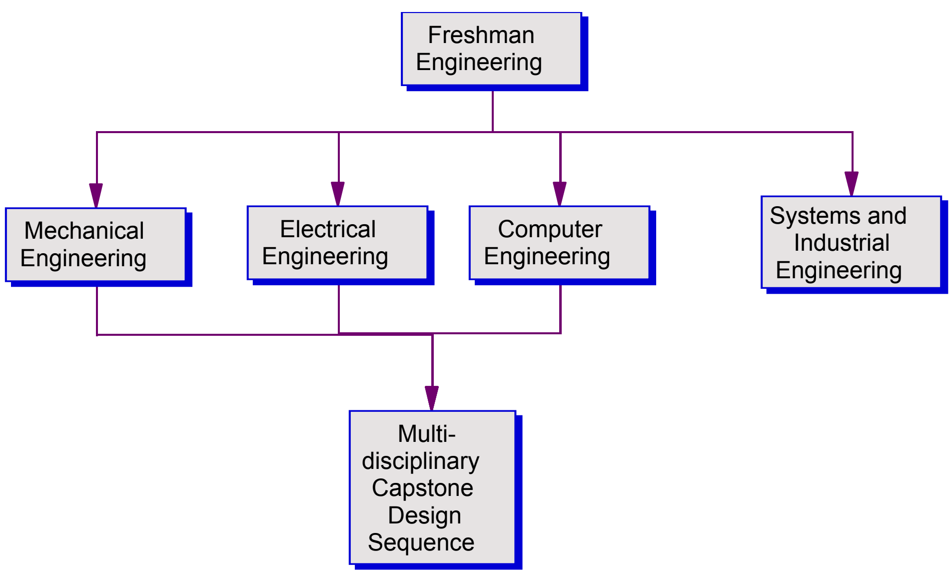

Figure 1. Common Freshman Year and Capstone Design Sequence in Watson School of Engineering and Applied Science

Background

According to Shepard [1], industrial employers have come to expect a certain level of both professional skills and professionalism from engineering graduates. There are a variety of qualities that engineers should possess upon graduation, each quality comprised of “competencies” (skills) and “attitudes” (perspectives) about each quality. Engineering educators focus on helping students attain these qualities through the process of creating a product or process in which students learn by “establishing objectives and criteria, generating alternatives, synthesizing, analyzing, constructing, testing and evaluating.” Although there are efforts to integrate design throughout the curriculum [2], most programs typically rely upon a senior level capstone design experience. A review of the literature in design courses at the senior level has yielded two broad categories: (a) courses focused upon meeting the needs of industrial customers, and (b) courses focused upon collegiate design competitions.

Todd, et al [3], have described an example of the industrial customer type at Brigham Young University. From the outset, the multi-disciplinary capstone design course was designed to address weaknesses in newly graduating engineers and makes them more able to help industrial customers compete in world markets. Industrial customers were surveyed to identify perceived weaknesses in engineering graduates with the resultant being a formatted capstone program that targeted the weaknesses. Students were treated as new employees of a fictitious company while the professors were treated as supervisors. Classes were termed training seminars. Students selected from a list of projects from sponsors who were willing to make significant financial and time commitments. The projects fell into three categories: product design, manufacturing process or equipment design, and systems integration. A formal design methodology, Clausing’s “Improved Total Development Process,” [4] was implemented, and a significant amount of oral and written work was required.

Paulik, et al [5], have described an example of the competition-based capstone design course. As a result of both ABET’s emphasis on teaching design throughout the curriculum and the appearance of design education texts, the authors chose to center the course around the Intelligent Ground Vehicle Competition for the following reasons: it is highly interdisciplinary; it affords undergraduate and graduate research opportunities; and it forces students to work under the pressure of a deadline. The course runs from January to August, with the actual competition occurs in June. Subsequent to the event, lectures focus upon the competition as a case study and apply topics such as legal concerns and economic cost analysis. Due to the nature of the competition, a shift towards the system level of design has occurred.

The present work seeks to add to the ongoing discussion focused upon multi-disciplinary capstone design. Several key differences exist between the present work and that described by earlier authors: A wide variety of possible projects are included for consideration and ultimately selection by student teams. Industrially sponsored projects are included as are collegiate-design competitions. Faculty and students are able to suggest their own projects with the only requirement being that an engineering faculty member agrees to serve as an adviser.

The course is used as a mechanism to focus on improving students’ oral and writing skills. Lastly, a dedicated and determined effort is made to address many issues that have been identified by ABET EC 2000 (Criterion 3 and 4) as important for tomorrow's engineers, namely engineering as an ethical profession and the impact of technology on the environment, and on society, both locally and globally.

Initial Offering

The course sequence, as stated previously, is a two-semester design experience that is worth four credit hours for each semester or a total of eight credit hours. By the end of the first term, students are able to: (a) work effectively in design teams; (b) interact professionally with clients and sponsors; (c) write a technically accurate and complete preliminary engineering design report; (d) use engineering project management tools; (e) make an effective preliminary design presentation; (f) perform an ethical analysis using moral reasoning theories; and (g) analyze the impact of technology on the environment.

The focus of the second half of the capstone design sequence is upon the completion of the project begun during the fall term. By the end of the second semester, students: (a) experience first hand the existential pleasures of the engineering profession through the successful completion of their respective design project; (b) produce an engineering report that documents their final product including engineering drawings, parts lists, budget information, vendor list, etc.; (c) make a polished and effective presentation of the final project; and (d) reflect upon the entire design experience, their educational experiences, and provide feedback to the engineering program.

During the first week of class, faculty advisers and external sponsors brief the seniors on the nature of their proposed projects and the financial support available. Students then sign up for the available projects listing their first three choices and proposed teams. By the end of the second week, the members of each of the teams are announced. After the projects have been assigned, each team provides the course director with a weekly activity report (WAR). The WAR accomplishes the following three important tasks: (a) it describes the progress made during the existing period since the previous report; (b) it reminds the reader what had been accomplished during the previous period; and (c) it describes the work that is to be accomplished during the next reporting period. The WAR also gives a brief synopsis of any and all meetings held with the project advisor and sponsor(s). The specific format used for the construction of the WAR is left up to each advisor and/or sponsor; the main requirement being that each maintains the highest professional standards.

At the end of the first two weeks, each design team provides the course director with a statement of work with timelines/milestone schedule. (An example of an acceptable statement of work with timelines/milestone schedule was provided in class.) At the end of the fall semester, each team provides a formal, written preliminary design report and makes a formal presentation of their project in an open forum. Prior to the final presentation, each team is required to perform a "dress rehearsal" for the course director and other interested faculty in order to insure the highest professional standards for the public delivery of the information. The specific format to be used for the written report is determined by the advisor and/or client(s) of the project team, the student design team, and the coordinator of the course.

Throughout the fall term, a limited number of lectures are held that focused on the following topics: (a) project management tools including PERT diagrams and Work Breakdown Schedules (WBS) [6]; (b) team dynamics and personality types [7]; (c) moral reasoning theories including utilitarianism, Kantianism and rights-based theories [8]; (d) engineering ethics and ethical case studies [9]; and (e) global and societal issues related to the growth of modern technology [10].

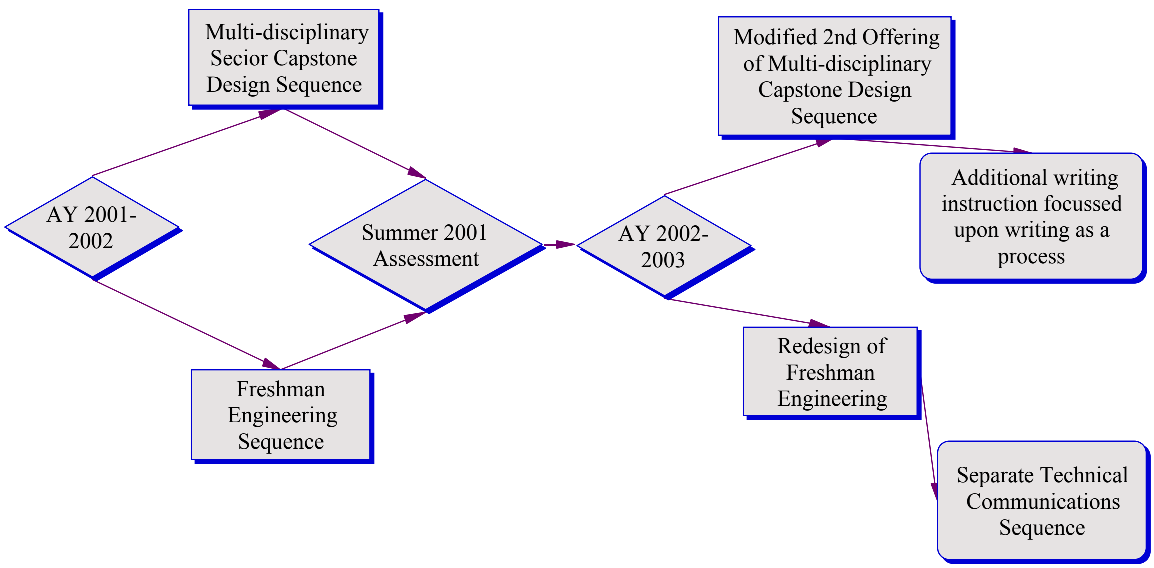

Figure 2. Interaction Between the Freshman Engineering Program and Senior Level Capstone Design Sequence

In support of the ethics component of the course, students are assigned two case studies and must formulate their recommended courses of action using a Utilitarian approach, a Kantian approach or a rights-based approach to the posed dilemma. (The particular case studies chosen for the first offering of the course were a consideration of the construction of the Aswan Dam [11] and the proposed authorization by the Bush Administration for oil and natural gas drilling in the Arctic Wildlife Refuge [12]. Analysis of the case studies led to significant changes both in the subsequent offering of the fall senior design course as well as in the freshman program. The analyses and subsequent changes are documented later in the present work.

No formal classes are held during the spring semester. Each design team must provide a WAR to both the course director and the team's faculty adviser and meet with their faculty adviser weekly. During the mid-term week, each design team meets with the course director to insure progress is being made and to discuss any difficulties. In addition, a formal mid-term in-progress review is required. As had been the case during the fall term, each team is again required to perform a "dress rehearsal" for the course director and other interested faculty in order to insure the highest professional standards for the public delivery of the information. The specific format to be used for the final written report is decided upon by the advisor and/or client(s) of the project team, the student design team and the course coordinator.

The final presentations for AY2001-2002 were made during the last day of the semester in a public event entitled, "The Celebration of Design." Each team was required to make a 20-minute presentation documenting their projects. The event had extensive university and local community press coverage for the event. Many university and local community officials attended and saw first hand the end products of the graduating engineering senior class.

Each team of students has an adviser from the engineering faculty. Each department judges the contribution of faculty members to the course uniquely. That is, each department chair has his/her own formula for calculating an "equivalent course load" for faculty who advise design groups. A successful student design project requires that the faculty member oversee and interact with the students throughout the project duration. The most critical factors for a successful project are communication and commitment. A minimum commitment of 1-2 hours per week by the faculty advisor is expected. The responsibilities of the faculty advisors include the following: (a) meet with the students regularly; (b) review regular reports (weekly or bi-weekly) to provide feedback from the faculty advisor's point of view (i.e., progress reports, project proposal, design analysis, final report); (c) evaluate the students' performance; (d) demand professionalism and a high level of performance from the students; and (e) attend the December presentation and the "Celebration of Design", the final project presentation during the last week of the spring semester.

For the externally sponsored and faculty-sponsored design projects, the project commitment fee is $1500 per student team. The cost for a second team working on the same project is $500. This fee serves as a budget for the group and has covered basic project expenses such as phone calls, faxes, copy charges, presentation materials, car travel to sponsor location, supplies and construction materials. A portion of this fee is used as overhead to cover the operating costs of the Division of Engineering Discovery and Design. The external sponsor or faculty advisor is expected to supply whatever physical resources are needed that were not already available at the university. Whenever additional resources or equipment are needed to complete the project, students must justify them by written proposal to the faculty advisor. For student-generated projects, each department pledges $100 per student. For example, for a team with two electrical and three mechanical engineering students, the electrical and computer engineering department pledges $200 and the mechanical engineering department pledges $300 for a total of $500.

Students and university personnel agreed to abide by the terms and conditions of the non-disclosure agreement entered into between the sponsor and university as evidenced by signature on a "Non-Disclosure Agreement Form". Prior to public disclosure of information including reports, display posters, and web pages, students agreed to provide the sponsor a copy of any proposed presentation for the sponsor's review and comment. Upon the request of sponsor, students agreed to remove all information identified as sponsor's confidential information. All project results are made available to the sponsor.

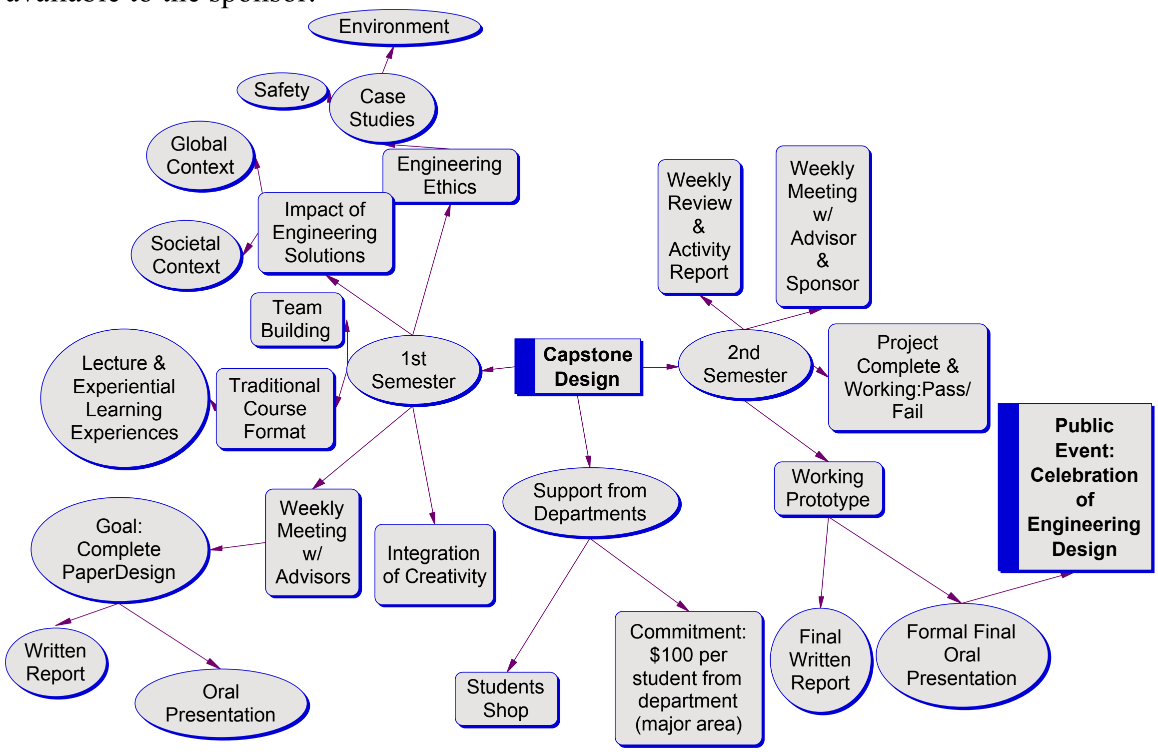

Figure 3. Proposed Model for Multi-disciplinary Capstone Design Course

In addition to restructuring the design course, a new grading schema was implemented. The projects are graded as acceptable (Letter grade "A"), incomplete (Letter grade "I"), or unacceptable (Letter grade "F"). From my personal experiences as an educator in various venues, I have found this grading schema to be effective in encouraging seniors to transcend the inevitable "senioritis." Additionally, the requirement that a project must be completed addressed many of the concerns expressed by industrial/corporate sponsors. In the past, outside corporate sponsors have been disappointed because their projects were paper designs only and as a result viewed sponsoring senior design projects as little more than a philanthropic gift to the engineering program.

The immediate student response to the grading schema was disbelief as seniors clung to the belief that both their passing and graduation were inevitable. The schema was discussed *ad homonym* and perhaps eventually *ad nauseum* throughout the fall term. It was not until the occurrence of the various "dress rehearsals" at the end of the first semester that students accepted that such a rigid standard was, in fact, the operating procedure for the course.

Feedback from student evaluation responses indicated that the students were excited about the freedom to suggest their own projects. They found this to be a significant improvement over the practice of earlier years when only externally sponsored projects were available for selection. Also, students representing SUNY-Binghamton had never participated in any collegiate engineering competition in the entire history of the school. During the first offering of the design sequence in AY2001-2002, teams competed in the *Society of Automotive Engineers' Mini-Baja*, *Super-mileage* and *Walking-Machine* competitions. In addition, one team competed in the *Applied Power and Electronics Control (APEC)* international competition and was the only collegiate team in a field of professional experts.

The case study assignments challenged students to come to a conclusion based on a moral reasoning theory; however, most of the papers contained only a simple argument based on pro's and con's regarding the issue. Although it was clearly stated that conclusions were to be focused solely on factual information, the students often merely gave their personal opinions. There were very few papers that actually took a theory, applied it, and presented an argument without subjective views. This revealed, first and foremost, the failure to understand the general concepts of the task.

The second major problem encountered was the lack of proper documentation. When reading through the papers, the same descriptive adjectives, verbs, and even whole sentences kept appearing. Many of the students cut and pasted entire paragraphs from various web sites into their papers without quotations or citations of sources of information. References using either the MLA or University of Chicago were required, though more often than not, neglected. Papers were written in an informal tone with phrases that were either conversational or more appropriate for e-mail.

A listing of the most common errors found in the essays include: (1) poor organization; (2) weak grammar skills, particularly punctuation; (3) subject/verb disagreement; and (4) inconsistency in verb tenses.

The mechanical engineering program includes a required project management course wherein similar (though not identical) tools are introduced as well as an overview of engineering codes of conduct. The students majoring in either electrical or computer engineering do not have an equivalent course. Thus, some mechanical engineering students thought that the inclusion of some of the topics was repetitive while nearly all electrical and computer engineering students thought that the pace of this section of the course was too rapid.

Second Offering

Because the writing skills of many of the graduating seniors were observed to be weak, many changes both within the context of senior design and in freshman engineering as well are introduced.

Engineering students at the State University of New York at Binghamton are not required to take an English writing class but rather have some limited instruction in the present freshman engineering courses. One of the immediate changes in the engineering program as a result of the multi-disciplinary capstone course was the introduction of two, required technical communications courses in the freshmen year. With more focused instruction on the writing process and with smaller classes (expected to be 25 students per section), it is hoped that students will have the opportunity to develop their writing skills to a much greater level of performance than has been the case previously.

Lecture Topics: AY 2001-2002	**Lecture Topics: AY 2002-2003**
Team dynamics and personality types	Team dynamics and personality types
Project management tools: PERT diagrams Work breakdown schedules	Project management tools: PERT diagrams Work breakdown schedules Objective trees Functional decomposition Black and transparent boxes
Engineering Ethics Codes Professional societies	Engineering Ethics Codes Professional societies
	Ethics in Design Green Design Sustainability
Moral reasoning theories: Utilitarianism; Kantianism; Rights-Based	Moral reasoning theories: Methods for Framing a Problem Utilitarianism; Kantianism; Virtue-based Rights-Based Case studies
	Honesty, Integrity and Reliability Case study
	Risk, Safety, and Liability Case study
Engineers and the Environment Case study: Arctic Wildlife Refuge	Engineers and the Environment Models of Nature Changing Myths of Science Idea of wilderness Life cycle analysis Case studies
Engineering and Societal/Global Impact Case study: Aswan Dam	Engineering and Societal/Global Impact Global engineering practice Global image and reality Global, national and local issues Case study: General Motors Joint Venture in Rural China

Table 1. Comparison of Lecture Topics between AY 2001-2202 and AY 2002-2003 (1st and 2nd Offering of Multi-disciplinary Capstone Design Course)

In the second year, the design sequence was set in a much more structured format with many formal, additional lectures held throughout the fall. A comparison between the two efforts is shown in Table 1. The focus held throughout the term is fixed upon providing students with the necessary “tools” to be successful as professional engineers both as problem solvers and as citizens of an ever more technologically dependent global society.

During the fall term, focused instruction by a team consisting of rhetoric instructor, graduate and undergraduate students majoring in English is included in the course activities. Emphasis is placed on writing as a “process” and on required revision and proper documentation for all papers. Students are allowed to revise their initial reports and essays and resubmit for a final grade. Though the decision to revise and resubmit is strictly optional, approximately 95% are re-submitted each time. A detailed breakdown of the assignments is provided in Table 2.

Writing Exercises: AY 2001-2002	***Writing Exercises: AY 2002-2003***
Weekly Activity Reports (10)	Weekly Activity Reports (10)
Preliminary Design Report (December)	Preliminary Design Report (December)
Final Design Report (May)	Final Design Report (May)
Ethics Cases: Arctic Wildlife Refuge	Exploration of Personal Values: Personal Narrative
Ethics Cases: Aswan Dam	Comparison and Contrast Essay (Dym, *et al*, p.53)
	Explain A Concept (Dym, *et al*, p.171)
	Describe a Process Essay (Dym, *et al*, p.263)
	Ethics Case: • Gilbane Gold (Case 21, Harris, *et al*. p. 313) • Oil Spill (Case 32, Harris, *et al*, p. 325) • Trees (Case 44, Harris, *et al*, p. 342) • Mere Technicality (Case 29, Harris, *et al*, p. 323)

Table 2. Comparison of Writing Assignments between AY 2001-2202 and AY 2002-2003 (1^{st} and 2^{nd} Offering of Multi-disciplinary Capstone Design Course)

Discussion of Results

A multi-disciplinary capstone course has been developed and taught for the last two academic years at the State University of New York at Binghamton. The course has provided insight into the strengths and weaknesses of the various engineering programs and students and has led to significant changes. Positive features that have resulted from the multi-disciplinary course are:

- Students from different disciplines are able to work effectively as design teams and successfully complete a major project on time and under budget.
- Students often work with faculty members as advisers who are outside their major departments.
- A positive relationship has been established with industrial sponsors as they appreciate the grading schema and its strict enforcement.
- Many of the issues raised in ABET's EC2000 Criterion 4 such as the impacts of engineering on the environment, society and globally have been addressed
- Students writing skills have been identified as extremely weak and concrete steps have been taken to address the weaknesses including the offering of a separate technical communications two-course sequence in the freshman year. In addition, plans are underway to include more opportunities for students to write in both the sophomore and junior years.

Many problems arose through the offering of a multi-disciplinary course. Perhaps the biggest issue focuses upon enlistment of faculty advisers, as without a formal policy on course-load equivalence for advising a design team, there will always remain a problem with finding sufficient numbers of faculty willing to take on additional burdens.
On a personal note, this is my second effort at developing a multi-disciplinary capstone course. [13] Perhaps Dickens was writing about a similar effort when he penned, "It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness." [14]

References

1. Shepard, Sheri D., "Design as Cornerstone and Capstone", *Mechanical Engineering Magazine*, January 30, 2003.
2. Hartman, David E. and Larson, Debra, "Design4Practice, 2000 ASME Curriculum Innovation Award Honorable Mention, www.asme.or/educate/cia.
3. Todd, Robert H., Sorenson, Carl D., and Magleby, Spencer P., "Designing a Senior Capstone Course to Satisfy Industrial Customers, *Journal of Engineering Education*, Vol. 82, 2003, No. 2, pp. 92-100.
4. Clausing, D. P., "Improved Total Development Process: Changing the Ten Cash Drains into Cash Flows," unpublished manuscript, MIT Laboratory for Manufacturing and Productivity, Cambridge, Ma. 1986.
5. Paulik, Mark J., "A Competition-Motivated Capstone Design Course: The Results of a Fifteen Year Evolution," *IEEE Transactions on Education*, Vol.44, No.1, February 2001.
6. Dym, C.L., and Little, P., *Engineering Design: A Project Based Introduction*, John Wiley & Sons: New York, 2000, pp.83-107.

7. Keirsey, D, and Bates, M., *Please Understand Me: Character and Temperament Types*, Prometheus Nemesis Book Co, 5th edition, November 1984.
8. Harris, C. E., Pritchard, M. S., and Rabins, M. J., *Engineering Ethics*, Wadsworth Publishing/Thomson Learning Center: Belmont, California, 2000, pp. 1-95.
9. Harris, C. E., Pritchard, M. S., and Rabins, M. J., *Engineering Ethics*, Wadsworth Publishing/Thomson Learning Center: Belmont, California, 2000, pp. 97-281.
10. Johnston, S.F., Gostelow, J.P., and King, W. J., *Engineering and Society*, Prentice Hall Inc.: Upper Saddle River, New Jersey, 2000.
11. El-Sayed, S. and van Dijken, G. L., "The Southeastern Mediterranean Ecosystem Revisited: Thirty Years after the Construction of the Aswan High Dam." *Quarterdeck* Vol. 3.1, Department of Oceanography, Texas A&M University, July 1995.
12. Chance, N., *The Arctic National Wildlife Refuge: A Special Report*, University of Connecticut, www.arcticcircle.uconn.edu/ANWR/anwindex.html
13. Catalano, G.D., "The Sunrayce `95 Idea: Adding Hands-On Design to an Engineering Curriculum," *Journal of Engineering Education*, Vol. 85, No. 3, pp. 183-200, July 1996.
14. Dickens, C., *A Tale of Two Cities*, Signet Classic: New York, Reissue edition (August 1997), p. 18.