A Hands-On Multidisciplinary Design Course for Chemical Engineering Students

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Abstract

Team-based design projects have seen an increased place in the chemical engineering curriculum, especially with the advent of the new criteria set forth by the Accreditation Board of Engineering and Technology. However, even with these efforts, two areas that are in need of more attention for chemical engineers are hands-on and multidisciplinary projects. Because of this, a new elective chemical engineering course at Michigan Technological University has been developed, CM4900: Interdisciplinary Design, to fulfill these needs for students as well as for students in other disciplines. In this paper there will be a description of course goals, the course structure chosen to achieve these goals, results from the first semester of this course (taught in the fall 2000 semester), and plans for improving this course in future semesters.

I. Introduction

During the 2000-2001 academic year, two new, unique engineering programs have been developed within the College of Engineering at Michigan Technological University. One of these is the "Engineering Enterprise," where students at the sophomore, junior, and senior level are combined into a business-like setting to work on a project. For example, the enterprise course taught by chemical engineering faculty is called "Consumer Product Manufacturing," where students are working on developing a product concept and carrying it out to the production stages. The industry sponsor for this course is the Kimberly Clark Corporation. Other enterprise projects within the College of Engineering include the Formula SAE Car, Pavement Design, Wireless Communications, and Ground Water Supply Evaluation.

Another set of new courses being made available to students at Michigan Tech includes design projects in departments outside their major discipline of study. These courses open to any student with a senior academic standing, are all at the 4900 and 4910 level and involve one- or two-semester projects including the Future Truck (Department of Mechanical Engineering – Engineering Mechanics), Clean Snowmobile (Department of Civil and Environmental Engineering), and Power Engineering (Department of Electrical and Computer Engineering) design projects. All of these courses are open to students in other engineering majors. The design project offered within the Department of Chemical Engineering is called Interdisciplinary Design, and is intended to span across traditional discipline boundaries. The development and implementation of this new course is the focus of this paper.

II. Learning Goals for CM4900: Interdisciplinary Design

The purpose of this course is for students to work on a team-based, hands-on, multidisciplinary design project. As such, students will be compensated (graded) at the end of the term according to their ability to meet the instructional course objectives:

- *List* the steps involved in the conceptual design process, *explain* their meaning, and *apply* them to a challenging design problem in interdisciplinary engineering
- *Create* a methodology to *select* and *optimize* a *proposed* design given a set of choices
- *Determine* (or *estimate*) how long various stages of the design problem take to complete and *propose* a timetable to meet the customer requirements for the design
- *Apply* engineering principles to develop a *model* for the design to *predict* system performance
- *Invent* a robust and functional prototype for the design problem
- Gain practical design ***experience*** through ***teamwork*** and a ***hands-on*** approach
- Develop a sense of ***responsibility*** to their design project and their design ***team***
- Demonstrate the working design, *explaining* key features and suggesting *improvements* given more time
- *Explain* (or *communicate*) ideas in both written and oral forms

Items listed in italics correspond to keywords for one of the six levels of Bloom's Taxonomy[1]:

1. Knowledge (list)
2. Comprehension (explain)
3. Application (determine, apply)
4. Analysis (predict, model)
5. Synthesis (propose, create, invent, improve)
6. Evaluation (select, optimize)

As development of a successful design requires knowledge from all levels of this structure, they are all included within the instructional objectives for this course. The lesser-used learning levels of analysis, synthesis, and evaluation are focused on within this course. It is also noted that three of the most important course objectives (listed in bold italics) fall outside of this hierarchy and into a separate levels required for a good design: hands-on experience, responsibility, and teamwork.

III. Course Structure: What does the instructor do with 5 contact hours per week?

During the first few weeks of the course, the students will be exposed to techniques and terminology that are used in formal conceptual design procedures (such as objectives trees and pair-wise comparison charts) to help them determine what aspects of the design are most important to the client and consumer. Material is taken from the design book titled Engineering Design: A Project Based Introduction by Clive Dym and Patrick Little[2], which provides an excellent introduction to the novice designer.

Following this introduction to the conceptual design process, sufficient technical detail (such as mass balances, electronic network analysis, and microprocessor programming) is provided in order for the students to comprehend the project and to gain an understanding of the design problem at hand. These lectures are especially instructive to students since a fair portion of the material is outside the range of expertise of their respective discipline. This is introductory material explaining the concept; the students are expected to use this information to their advantage in formulating a design to meet the objectives of the project.

After developing a proposal report, the student teams (under the direction of the fictitious company, CM4900.com) will be given a modest budget and fabricate a working prototype that meets the design objectives and user requirements while satisfying all required functions subject to any necessary constraints. The course culminates with a final report and a proof-of-concept demonstration.

The design project for the first semester of this course is the control (chosen because of its universal place in most engineering curricula) of a bench-scale chemical process (chosen because this is a course offered in the Department of Chemical Engineering). In later sections, this paper will present a portion of the report from a student design team ("JNC Design Team" of Charu Dugar, Janelle Meyer, and Nakeya Norman, all senior engineering students at MTU) worked on during the Fall 2000 academic semester, and visions for future course improvement.

IV. Interdisciplinary Design at Michigan Tech during the Fall 2000 semester

In this day and age of internet start-up companies and hotly traded IPO's a new star is born: the chemical consulting company called CM4900.com. Students enrolled in this course are put on the payroll in the hopes of striking it rich. The final compensation is not dollars and cents; rather, students are compensated with letter grades on their report cards. The client: Huskie Industries International (a.k.a. HI^2, named in honor of Michigan Tech's sports teams, nicknamed the Huskies), a leading chemical company, which makes anything and everything (sort of like the Acme company from Road Runner cartoons) in our fictitious dream world.

IV a. Description of "The WIN MTU Design Project"

During the Fall 2000 Semester, HI^2 has contracted CM4900.com to produce an automated chemical delivery production facility known as a "Widespread Industrial Novel Multifluid Turnout Unit (a.k.a. WIN MTU). HI^2 has received numerous awards for their environmental awareness while producing a high-quality mixture of three fluids:

- huskanic acid (distilled water)
- dihockey ether (distilled water with 1% by mass added salt)
- the patented Keweenaw ketone (distilled water with 1% by mass added red food coloring)

These mixtures may be used by clients of HI^2 as stock material for either producing novel industrial or pharmaceutical chemicals, or for purifying an existing chemical process.

In the past, the fluids were mixed by hand according to client specifications and placed in shipping "tankers" (plastic vials). However, statistics showed that the orders placed to HI^2 were of random concentrations of the three ingredients and that quality control was low. Consequently, CM4900.com was contracted to develop a design and prototype for a low-cost, automated chemical delivery production facility capable of meeting client needs yet being of superior quality.

IV b. Special Considerations and System Performance Requirements

The client (HI^2) has mandated the following special requirements from the employees of CM4900.com:

- the stock fluids must be prepared by the groups
- each stock tank must have an open top so that management can "perturb" the purity of the input
- the "piping" exiting each stock tank must have a manual shutoff so that management can "perturb" the maximum available stock flow rate (this also permits for an "emergency shutoff" which is a safety consideration for these compounds)
- the design must include a "product control room" with dials or buttons that can be adjusted to turn the system on and off and and change the desired product concentrations
- the design team will be supplied with a BASIC Stamp II microprocessor, Stamp II servo controller, and several servo motors (manufactured by Parallax, Inc.)
- design teams will be given a budget of $150 for equipment, and may also spend no more than $100 of their own money
- a detailed budget for all costs should be proposed in the DPR and a final budget should appear in the FPR as appendices.

These special requirements are meant to act as "constraints" to the student design problem. The student design teams have total flexibility in their designs with the exception of these special client-mandated design features (such as idiot lights on cars when your seat belt has not been fastened or your oil is a quart low).

IV c. Team Assignments

The students enrolled in the course will be broken up into teams of three or four students. The groups will be chosen by project management (course instructor) to be as multidisciplinary as possible. Each team will be responsible for designating a job title for each team member, assigned according to the following breakdown:

- (one) Project Manager who will have the responsibility for overall coordination of the team efforts including budgeting, setting a project timetable, and resource management.
- (one or two) Senior Engineers who will have the responsibility for the coordination of work to be done on all or some of the sub-systems, which make up the design. The number of senior engineers per team will depend on the size of the team.
- (one) Manufacturing Director who will have the responsibility for coordinating the fabrication of the prototype.

Students do not need to make these job assignments immediately; rather, management recommends that they work together on the project for a few weeks before making a decision, as some of the team members are better suited for a particular job description. These assignments are only to guide student design team towards success on this project, and are told that no one job is either superior or inferior to their counterparts.

Each group member will be responsible for dividing the total work on the project in a way that is fair to all of the other team members. Management strongly recommends the subdivision of the main project into several components. How the project is subdivided is up to the group members, but each component or subdivision should have at least two personnel working together on it to allow for maximum collaboration between all of the team members.

The idea behind the team job assignments is twofold. Most importantly, students are reminded as they work on this project throughout the term, they can't do everything by themselves; only with teamwork will any professional engineering project be successful. Secondly, students gain some insight into project (by subdividing the project into small tasks to be performed by sub-teams) and personnel (by having responsibility for a specific aspect of the design project) management techniques.

IV d. Student Deliverables

In order to meet these goals, specific deliverables are required of students in both individual and team formats. These deliverables are a modified list from successful design classes the instructor had experience with while a graduate student at the University of Notre Dame[3,4].

The salary (grade) for students enrolled in the course is based on the performance of their design team as well as their individual effort towards the success of the design team. The specific items required by management during the term of the project are listed in the following table:

Deliverable Item	(G)roup or (I)ndividual	Portion of Final Grade
End-of-term lab notebook	I	10%
End-of-term peer evaluations	I	20%
Weekly memo reports	I	10%
Mid-term proposal report	G	20%
End-of-term final report	G	20%
End-of-term prototype demo	G	20%

Each of the deliverable items are discussed in detail below:

<u>Weekly memos</u>: Each individual will be responsible for composing a memorandum to be turned into management by noon each Friday (unless there is a university holiday). The memo should focus on the work that the student and their team has done on the project since the previous memo, and must follow proper format requirements (be typed in 12 point font with one inch margins and be no more than two pages excluding graphics).

Design Proposal Report: Each group will be responsible for composing a Design Proposal Report (DPR), which is composed of written and oral portions. The written report (due at the beginning of the sixth week of classes) should not exceed ten typed pages excluding graphics and other supporting material, which may be placed in an appendix. The oral report (to be given at the end of the sixth week of classes) should last fifteen minutes with an additional half hour available for questions.

The DPR should accomplish the following:

- discuss the purpose of the design project and prototype
- describe the design parameters that are available for your team to change and/or control for this project
- discuss any constraints such as
    - potential design parameters that cannot be changed or controlled
    - limitations on the design parameters
    - limitations on system performance
- determine criteria to evaluate the design performance

Once these items have been discussed, the DPR should then:

- outline a proposed design to meet the project requirements
- compare and contrast the design proposed by your team with other designs that were considered
- justify the choice of your proposed design through sound, technical engineering analysis while taking into account material and budget availability as well as the environmental impact and safety of the proposed design
- predict the quality and quantity of the product being produced

Management will then decide if the project is feasible, approve funding for prototype construction, and compensate your team accordingly.

Final Project Report: Each group will be responsible for composing a Final Project Report (FPR). The FPR, like the DPR, is composed of written and oral portions. The written portion must not exceed twenty-five typed pages excluding figures, tables, and appendices. The final oral report should last about fifteen minutes and is open to the general public (a.k.a. the "Board of Directors"). Fifteen minutes of questions will follow the oral report, given at the end of the term.

The FPR should accomplish the following:

- a brief review of items satisfied in the DPR
- a discussion of any design changes that were brought about after prototype construction was begun. This should include supporting engineering analysis if deemed appropriate
- a technical manual describing the composition and construction of the prototype and its key components
- a discussion of experiments performed with the prototype and comparison with simulated results. The discussion should also address the predictions made by the design team in the DPR for the quality and quantity of product produced

- conclusions and recommendations for further study with this design including industrial scaleup

The FPR must also contain a one-page executive summary which overviews both the key goals and results of this project. This summary should stand alone in its descriptions and clarity as copies of the executive summary will be distributed to and evaluated by the "Board of Directors". Copies will also be distributed to the public at the oral report.

Prototype Demonstration: Design teams will be required to demonstrate their prototype to course instructors and to the general public (two demos are required, since by Murphy's Law at least one of them will not work).

Peer Evaluations: Peer evaluation forms will be provided to student towards the end of the semester. Students evaluate the performance of their teammates on this form. As the peer evaluation is 20% of student compensation, it can affect a final course grade by *at least* one letter grade! If students work hard and in a professional manner with their teammates, it should be a free twenty points.

Management reserves the right to fine employees (give a failing grade) to those who exhibit a large degree of unexcused absences to team meetings or who fail to give their share of effort to their teammates and their design project.

Lab Notebook: Over the course of the term, students are required to keep a lab notebook. It should be a hardcover lab notebook with bound pages numbered sequentially. The notebook should include written ideas, thoughts, sketches, calculations, timetables, notes from group meetings, notes from phone conversations with vendors (along with names, phone numbers, part numbers and prices of items you are considering for purchase), or anything else of value. When an idea is written down, it should be marked with the date and time in the margin.

Such lab notes are commonly useful for protection and documentation of work performed in an industrial or academic patent application. The notebook should be considered a "course diary" of all activities pertaining to a team's design project. Emails or graphs are allowed to be taped to the pages of the notebook but the contents of the notebook should not fall out.

IV e. Results of Student Design Project – "The WIN MTU Mixing System"

The following are portions from the Final Project Report from the "JNC Design Team" composed of Charu Dugar (Project Manager), Janelle Meyer (Senior Engineer), and Nakeya Norman (Manufacturing Director), all senior chemical engineering students at Michigan Tech. The principal author has edited the text for typographical and grammatical errors as well as the occasional technical error.

JNC Design Team **Executive Summary:**

> The "Widespread Industrial, Novel Multi-fluid Turnout Unit" (WIN MTU) project is to develop a design and prototype for a low-cost, automated chemical delivery

production facility capable of producing a high quality mixture of three fluids (huskanic acid, dihockey ether and Keweenaw ketone).

Huskie Industries International (HI^2) needs to construct an automated chemical delivery production facility to produce a high quality mixture of three fluids at low cost. Currently, HI^2 is making their products by hand mixing according to client specifications; however, the product made is of low quality. The JNC Design Team decided the design should be safe, efficient, useful and as inexpensive as possible.

We chose a design option where the stock solutions flow directly into the final mixing container. This was chosen due to economic considerations over an alternative design where the stock solutions would flow into an intermediate container of known volume prior to entering the final mixing container. In our final design, we had planned on having the solutions enter the final mixing container one at a time. In order to get an accurately measured product, this would mean that we would need a way to measure the amount coming directly out of the stock solution container. Instead of this, we implemented a control loop using a sensor (photoresistor), actuator (stopcock valve), and a controller (Basic Stamp microprocessor).

We did not meet the given objectives for this project due to various setbacks. The prototype we built is in semi-working condition. However, limited experimental trials were performed to verify the functionality of the prototype. The experiments and the Basic Stamp computer programs demonstrate that with further evaluation the prototype can be improved for the desired objectives.

The JNC design group believes this is a good simulation of the HI^2 facility and that with more time we can complete the prototype. After, the prototype is tested and meets the client/engineering statement it should be considered for a scale up to an industrial level.

During the course of the project we broadened our electrical engineering, computer science, and mechanical engineering skills. We believe we have learned interdisciplinary concepts and that we can apply this knowledge to future projects.

<u>Excerpt from **Engineering Analysis** Section</u>

Schematic of Final Design:

A schematic for the final design is shown below in figure 1. The tank on the left contains huskanic acid (pure distilled water) and the tank on the right contains Keweenaw Ketone (distilled water with 1% by mass red food coloring). A third tank which was supposed to contain dihockey ether (distilled water with 1% by mass salt) is not shown. This product was eliminated from the prototype as the conductivity meter was on backorder during prototype construction.

The Basic Stamp II Microprocessor:

The Basic Stamp II Microprocessor is the brain and central nervous system of the prototype. We download our program, written on a personal computer, into the microprocessor, and then executed the program. This program reads external inputs to the system (potentiometer and photoresistor resistances) and stores them as variables.

The first input device is a potentiometer. This works the same as a tuner button. While a tuner button changes a radio frequency, the potentiometer changes resistance. There is a carbon disk inside, which has three metal "wipers" placed on the disk. The outside wipers are stationary. The turn dial moves the middle wiper. As the dial is turned, the resistance between an end and middle wiper changes. There are eleven settings that the dial can be turned to and each settings has a certain corresponding resistance. A picture of the potentiometer is shown below in Figure 2.

The potentiometer resistance is interpreted by the microprocessor as corresponding to a desired fluid concentration of Keweenaw ketone (water with 1% by mass red food coloring). We can dial in the desired concentration of the ketone using the potentiometer.

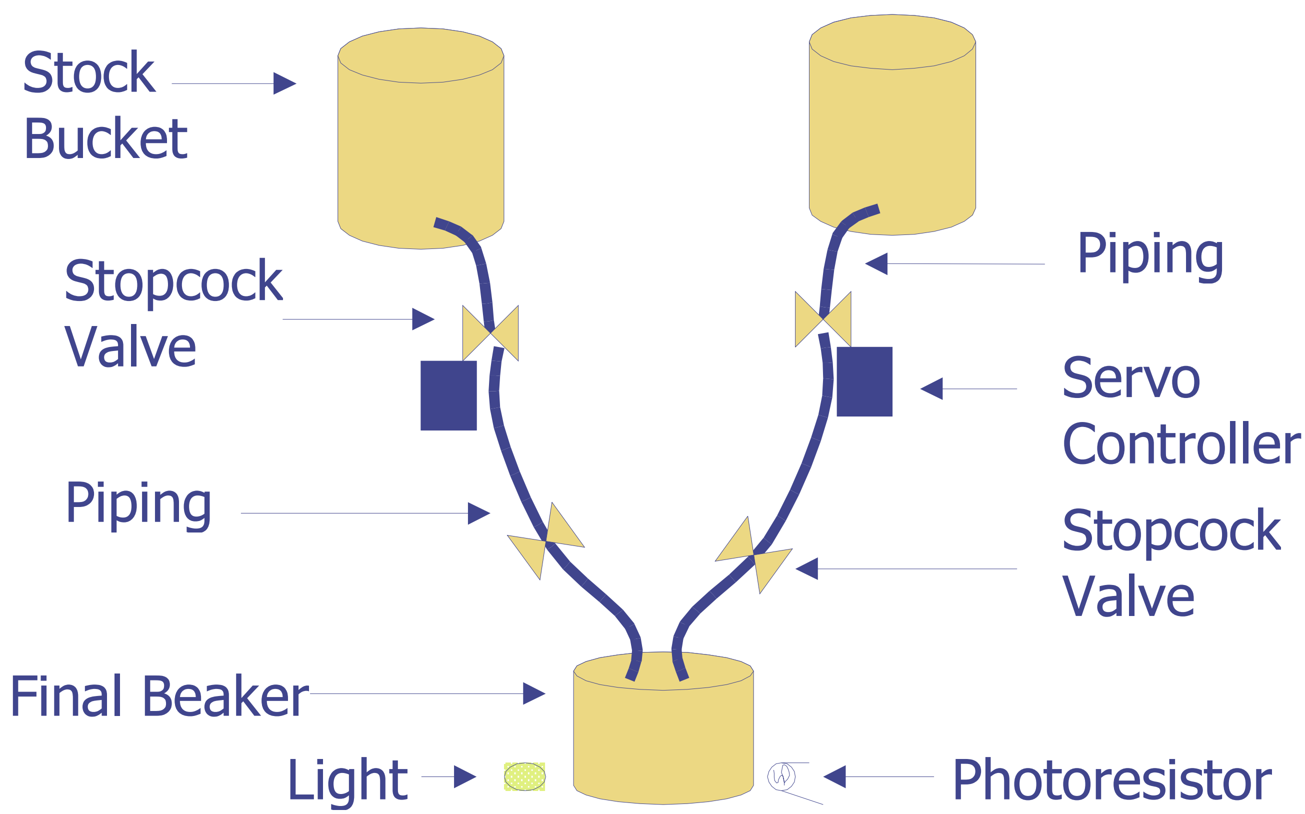
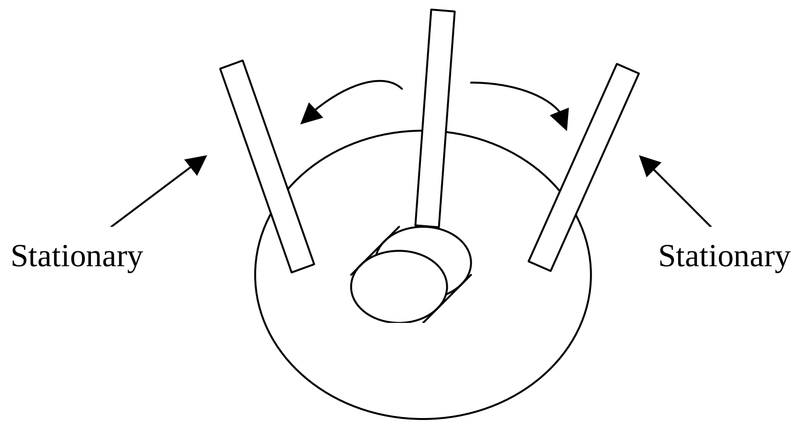


Figure 1: Schematic of Final Design



From this dial setting, the stopcock valves would be adjusted via a feedback control mechanism. Because the flowrate through the stopcock valve was almost zero for small adjustments of the valve, an on/off controller was implemented.

The second input device was a photoresistor. It was used in our prototype to measure the light intensity of the fluid in the tank, essentially serving as a color sensor. We have a light shining through one side of the final mixing container. The photoresistor is on the other side of this beaker. As the light shines through, a resistance is measured by the photoresistor, depending on the amount of light that travels through the mixture. A picture of this is shown below in Figure 3.

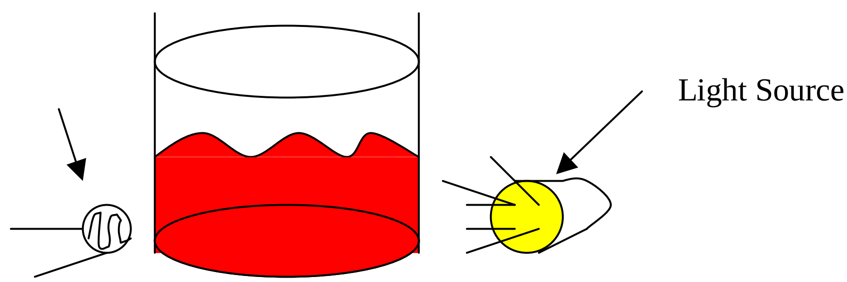


Figure 3: Photoresistor

We calibrated this photoresistor with different concentrations of red food coloring in water. These values are stored in the microprocessor program in the same way the potentiometer values are. We know apporoximately what the values should be for our desired concentration. The microprocessor will know what the value should be and, during operation, it will measure and check to see if the value is correct. If it is, a subroutine will be called to have a light emitting diode come on to tell the operator that the mixture concentrations are correct. If the concentration is not correct, a servo controller interfaced with the microprocessor will control the motion of the servo motors.

V. Suggestions for Future Improvement (i.e. what the instructor did wrong)

It is well known that most people learn best by doing rather than by listening. This is the reason why this class has a hands-on emphasis. By actually going into the lab and "getting their hands dirty," students learn more than the instructor could ever tell them. Teaching such a hands-on design class for the first time also allows the instructor to gain some "real-world experience" in teaching such a unique course. In this section the instructor will share some insights as to what went wrong and how it is hoped these problems will be avoided in future years.

Some of the problems that arose during this course are the following:

- *Teams not interdisciplinary:* The majority of students who enrolled in a design course remained within their major discipline. Better coordination between design faculty may allow the development of true interdisciplinary projects. A secondary effect may be the development of interdisciplinary research collaborations throughout the College of Engineering as well.

- *Lack of student ownership in the project:* Students had a tendency to "put off" their work on this course in favor of the strict requirements of their senior Plant Design and Unit Operations Lab courses. These are "required" courses in the Chemical Engineering curriculum and the instructor knew that they would be busy spending a great deal of their time on them compared with an "elective" design course such as Interdisciplinary Design. The course was promoted as one that does not have exams or much homework to attract additional students.

  There was too long of a lag period in between due dates on deliverable items, with the exception of the weekly progress memo. Thus, there is difficulty for the instructor in gauging how the students are keeping on track with respect to the project. Having specific, intermediate deliverable items is a must to ensure the students maintain focus, especially with the large burdens senior Chemical Engineering students carry with their other courses. This will be instituted in next year's course.

- *Streamline lecture material on conceptual design issues:* The introductory information on conceptual design was useful to the students in creating ideas for the design project. It also was useful to one student who was also enrolled in the Engineering Enterprise course called "Consumer Product Manufacturing." However, this was the first course that the instructor has ever taught and it was difficult to estimate how much time it would take to cover this material. It was believed it would take two weeks – in reality it took four. This material can be condensed by removing extraneous information and requiring the Dym and Little text for all the students. They can then read it on their own time and use it as a reference material that will aid them during the preliminary design phase of the project.

- *Development of better tutorials to demonstrate new concepts necessary for completion of a successful design:* Student groups suggested "hiring" a computer scientist (to help with microcomputer programming and MATLAB programming for dynamic numerical simulations), a mathematician (for the theoretical development of simulation tools), an electrical engineer (to wire all the circuitry for the microprocessor and control system) and a mechanical engineer (for help with using the servo motors and construction of the working prototype). The instructor tried to help the students towards the end of the semester with these areas, but will try to help them along the way next year. The implementation of intermediate deliverable items will help both the student and instructor stay on pace in future years.

- *Failure to satisfy specific design requirements:* The students had difficulty interfacing the "real world" portion of the course, (pertaining to the development of a design and construction of the prototype) to the "ivory tower" portion (pertaining to the development of dynamic modeling tools). They did not recognize they were supposed to use their models and experiments in concert to optimize their design. A working example will be developed in future years to help illustrate these concepts.

Overall, the students met most of the course objectives, even stating in their executive summary gaining familiarity with interdisciplinary design issues. They did very well at satisfying the lower levels of learning from Bloom's taxonomy (knowledge, comprehension, application) but had some difficulties reaching the higher levels (analysis, synthesis, evaluation), although they gained considerable exposure to them. Aided by the insight gained from last year's shortcomings, described in the above discussion, future students should do even better with their designs. It is also hoped in future years to collaborate with a faculty member in another department at Michigan Tech to truly give the students an interdisciplinary design experience.

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