AC 2011-1485: DEVELOPMENT AND IMPLEMENTATION OF AN INTERMEDIATE DESIGN COURSE USING ACTIVE LEARNING

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Development and Implementation of an Intermediate Design Course Using Active Learning

Abstract

Six years ago, the Mechanical and Nuclear Engineering Department at Penn State, after many heated debates, approved a major curriculum change that included adding a required course in Design Methodology. This action was taken to better align with ABET curriculum objectives, particularly in the area of Design. The course was designed from a set of learning objectives and emphasizes design thinking, decision making, and professional skills including communications and effective teaming. A concurrent approach is used, where theory and application are presented simultaneously, using the design process as the underlying framework. Students are exposed to design in a variety of contexts through in-class examples, case studies and hands-on projects. The major challenge of this course is to offer a high-quality design experience to over 300 students per year in multiple sections with multiple instructors. Several assessment tools were employed to assess student self-efficacy and skill development. This paper discusses the development, operation, and results of the course.

I. Background

1.1 History of Curriculum Change in Mechanical Engineering at Penn State

The B.S. Mechanical Engineering program at Penn State graduates approximately 250 students each year. The forty full-time equivalent faculty in Mechanical Engineering teach the ME courses and are also expected to be active in research in their area of specialty. 40% of the faculty have had direct experience in industry. Students are admitted into the ME degree program after the fourth semester. Approximately 60% of the students in mechanical engineering start at the University Park campus while the others start at one of eighteen branch campus locations. Since required courses in the first two years of the program must be available at all campus locations, the curriculum cannot have specialized mechanical engineering courses in the first two years. The B.S.M.E. curriculum contains 131 semester credits.

The Department of Mechanical and Nuclear Engineering (MNE) is heavily involved in curricular improvement, both in the college and in the department. College level programs such as the NSF-funded Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL), the Learning Factory, and the Leonhard Center for the Enhancement of Engineering Education have benefited from the involvement of departmental faculty in leadership positions. These organizations have inspired several department-level demonstration projects that have been highly successful. Through these initiatives, cost-effective ways to incorporate active learning into MNE courses have been developed, with demonstrated improvements in student learning. Motivated by a number of factors including the ABET Engineering Criteria 2000 (EC2000), student surveys, and feedback from our industry advisory committee, the department is currently working to incorporate and implement these teaching innovations across the curriculum. Although courses and teaching methods are regularly updated and modified, a major change in the B.S.M.E. curriculum had not been made since the mid 1980's.

In January 2004, a curriculum improvement effort was launched with the objectives shown in Table 1.

Table 1. Curriculum Improvement Objectives for Mechanical Engineering

1) Improve Delivery - To encourage deeper student learning by:
   - a. Integrating theory with practice
   - b. Integrating concepts across courses
   - c. Requiring fewer courses/semester to increase depth
   - d. Enhancing lifelong learning skills

2) Enhance Content - Increased student exposure to:
   - a. New and emerging technologies
   - b. Professional skills (societal impact, ethics, team skills, project management, global issues, economic justification)
   - c. Computer and numerical skills
   - d. Design methodologies and tools

Following intensive discussions and two faculty retreats, a major revision of the Mechanical Engineering curriculum was approved in October 2004 as outlined in Table 2. A description of the process and the resulting curriculum changes is described by Pauley et al.[1].

Table 2. ME Curriculum Revision

Remove from degree requirements:	Kinematics (3 cr), Thermo II (3 cr), Statistics (3 cr)
Modify:	Instrumentation (from 3 to 4 credits, adding applied statistics)
	Senior Capstone Design (from 4 to 3 credits)
Add:	Design Methodology (3 credits)
Total Credits:	131 (formerly 137)

The curriculum revisions resulted in the creation of an intermediate design course and eliminating courses in Kinematics and Thermodynamics II. Previously, ME students would take two "bookend" courses in Design (at the beginning and at the end of their degree program):

<u>Cornerstone course</u> – Freshman year introduction to design and graphical communications, common to all engineering disciplines (3 credits)
<u>Capstone course</u> – An industry project clinic taken in the senior year, course topics include: structured design process, team skills, project management, prototyping, industrial design, professional communications, ethics, and project economics (4 credits),

In the time between their Freshman and Senior years, students undertake intense theoretical study, where every problem is well-posed and has only one correct answer. Then in the senior year we task them to complete an industry sponsored, open-ended problem that they could not look up in their textbooks. We were "shocked" to find that many of them floundered. As taught until 2004, the bulk of the senior capstone course was devoted to design material that had been lost or forgotten in the previous two years, and students had limited time to actually work on their project. Feedback from industry project sponsors indicated a need to change. Students tended to lock onto the mission, and lost sight of the underlying knowledge and skills that would enable them to complete their *next* project assignment. We learned that the last semester is too late to instill the philosophy that design is a compromise between conflicting technical, social, and economic criteria; that there is usually no one best answer; that a practicing engineer seldom has all the information or time necessary to make the proper calculation – *Better is the Enemy of Good*.

1.2 The Importance of Design in Engineering Curricula

The emphasis on Design in engineering curricula has dramatically increased in the past two decades. This has occurred in response to the realization that curricula had become too abstract and theoretical. Employers expressed a desire for engineering graduates with a strong technical foundation, and more professional skills including design, communication and teamwork [2,3]. ABET encouraged this transition with new accreditation guidelines. ABET 2000 criteria requires that engineering programs demonstrate that their students: c) *attain an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.* In the early 1990's, The National Science Foundation made major investments in Engineering Education Coalitions (such as ECSEL, Gateway, Foundation, SUCCEED, SYNTHESIS) to foster curriculum innovation. Other institutions, including Virginia Tech [4] and University of Texas at Austin [5], have identified and addressed the need for an additional project-based design course between freshmen and senior years.

II. Course Overview

The primary mission of the Design Methodology course is to reinforce and expand on the foundation laid in a Design and Graphics course taken in the first year, and better prepare students to satisfy an industrial client in the senior capstone course. It is intended to help fill the void in the 2nd and 3rd years, where students were pre-occupied with lecture-based, fundamental courses, with little opportunity to design or practice.

The course was designed from a set of learning objectives and emphasizes design thinking, decision making and professional skills including communications and effective teaming. The specific learning objectives are listed in Table 3. This course endeavors to strike a balance between the art of design and the science of design. A concurrent approach is used, where theory and application are presented simultaneously, using the design process as the over-arching problem solving method. A just-in-time approach is followed, where the class material is designed to satisfy a need for knowledge to complete an activity or project. When students have a problem that they are trying to solve, they actually want the knowledge, will use it immediately, and are far more likely to be able to remember and transfer that knowledge later to a different application. When technical content is taught without application just because someone else (i.e. the instructor) thinks it is important, students file it away in their mental folder titled: "I can look this stuff up later if I ever need it". This assumption must be tested somewhere in the student's academic career and its limits must be determined. As an old Welsh proverb says: *An early stumble saves a later fall*. Open-ended design problems provide motivation and an opportunity for students to develop good judgment and confidence in their abilities as an engineer.

Table 3. Learning Objectives – Design Methodology for Mechanical Engineers

1) Instill the philosophy that real engineering design is often an open-ended, ill-defined process
2) Provide students with in-depth practice in design and the use of a structured approach to design
3) Develop and practice teamwork, critical thinking, creativity, and independent learning
4) Develop and practice communication skills (verbal, written, electronic)
5) Reinforce and improve CAD/Solid Modeling skills
6) Develop and practice skills in project planning, budget management, resource allocation and scheduling
7) Instill a philosophy of professional and ethical behavior
8) Provide guidance in applying engineering principles to open-ended problems
9) Provide an introductory knowledge of business practices, economic viability, environmental sustainability, and the social consequences of technology

Most of our students are not as abstract or reflective as the typical professor, and learn more effectively in more active modes. Dale [6] reports that after two weeks, people generally remember 10% of what they read, 20% of what they hear, 30% of what they see, 50% of what they hear and see, 70% of what they say, and 90% of what they say and do; similar figures are given by Stice [7]. In a large study of Physics courses [8], interactive engagement was found to be superior to traditional teaching methods (passive lecture, recipe labs, algorithmic-problem exams) in promoting conceptual understanding. An excellent overview of active learning research was compiled by Prince [9].

III. Implementation

3.1 Class Delivery

Recognizing the importance of continuous exposure and practice in design, the primary motivation for the intermediate design course is to reinforce and expand on the foundation laid in the Freshman year and provide a strong foundation for the senior capstone project. It is now a required course for all Mechanical and Nuclear Engineering majors and is typically taken in the 6^{th} semester. The current text is Product Design and Development, by Ulrich and Eppinger [10]. This text focuses on the business aspects of product design. This is supplemented with more discipline-specific handouts and invited external speakers.

Every class meeting (1 hour 55 minutes long, twice per week) consists of a brief presentation or workshop, and a hands-on activity to illustrate that material. The section size is limited to 30 students. Students are required to keep a design journal following professional standards for documenting intellectual property. Reading assignments from the text are required and are encouraged by brief quizzes. The book is self-explanatory and not difficult to comprehend. If the instructor does not have to narrate the text with boring Powerpoint slides, precious classroom time can be more productively used applying and reinforcing the material via real examples and activities.

Recognizing that students may not find lectures to be as interesting as the instructor may hope, their length is kept to a minimum, and every effort is made to make presentations multi-modal and participatory. Active learning exercises such as Think/Pair/Share [11] are interspersed into lectures. Several video and audio clips have been purchased to provide a change of pace and a different voice than the instructor's. A typical class session would consist of a brief presentation by the instructor (30 minutes or less) providing background, context and information needed for an in-class activity. In preparation for each session, students would have been assigned some reading and the completion of some discussion questions. Students are required to record their activities and a reflective essay on these sessions in their journals.

3.2 Project-Based Education

In this course, students are exposed to design in a variety of contexts, including customer-driven and technology-driven products, through in-class examples, case studies and hands-on projects. In the first half of the course, case studies and small design activities are employed to illustrate the design process and to prepare for a major design project. Preparatory activities less than one class period in duration include creativity exercises, brainstorming, patent search, case study videos and discussions, ethics role playing, team survival exercise, industrial design assessment of disposable razors, and a DFM (Design for Manufacturability) analysis of a VCR tape or a Nerf dart gun.

3.2a Mini-projects

To prepare students for a major design project, two mini-projects are completed in the first third of the semester. These mini-projects are completed in two to three class periods and require the preparation of a short report with data, analysis, and conclusions.

<u>Reverse engineering and manufacture of a bracket assembly.</u> This project requires each team to measure and machine one part in a two-part aluminum bracket assembly as shown in Figure 1. The project is divided into three steps. Step 1: Measure an existing bracket part and prepare a dimensioned engineering drawing. Step 2: Machine the other bracket half using the engineering drawing that another team prepared. The machining was done outside of class time and it was required that each team member contribute to the machining. Step 3: Inspect the part that was machined by another team following your team's engineering drawing. Try to fit the part to the mating part. If they do not fit (as is usually the case), perform a root cause analysis to determine the source of the problem. This project requires 3 class periods to complete. It provides an excellent foundation in basic machining practices and a dramatic demonstration of the importance of dimensional tolerances.

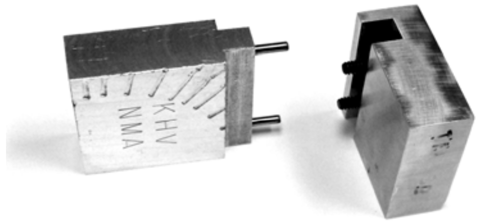


Figure 1. Students reverse engineer and manufacture a two-part aluminum bracket assembly. The majority of student-manufactured pairs do not fit together – illustrating valuable design lessons of the importance of proper tolerances and designing for ease of assembly and manufacture.

<u>Dissection and benchmarking of electric hand drills.</u> This project involves the dissection, testing and benchmarking of 3/8" power drills from various manufacturers such as Black&Decker, Dewalt, Hitachi, Chicago (cheap knockoff of the Milwaukee brand). The drills cover a wide range of cost ($10-$60) and performance. This project requires two class periods to complete. In the first class period, each team dissects one drill as shown in Figure 2. They also inspect the other drills to observe differences in components, assembly, and features. In the second class period, each team tests the performance of a drill using a dynamometer, power meter, and tachometer as shown in Figure 3. Using data collected from all teams, a summary table is prepared to compare the performance of all drills and to identify the "best in class". Drills are purchased at local hardware stores. Depending on their complexity and quality, they can be disassembled and re-assembled multiple times (3 or more) before sacrificing their lives to science. One sample of each drill which has never been dissected is kept for testing. The learning outcomes of this project include: basic understanding of mechanical and electrical components, measurement techniques, dissection as a design tool, and competitive analysis.

Figure 2. For many students, the drill dissection is their first experience using tools or tinkering with mechanical or electrical hardware.

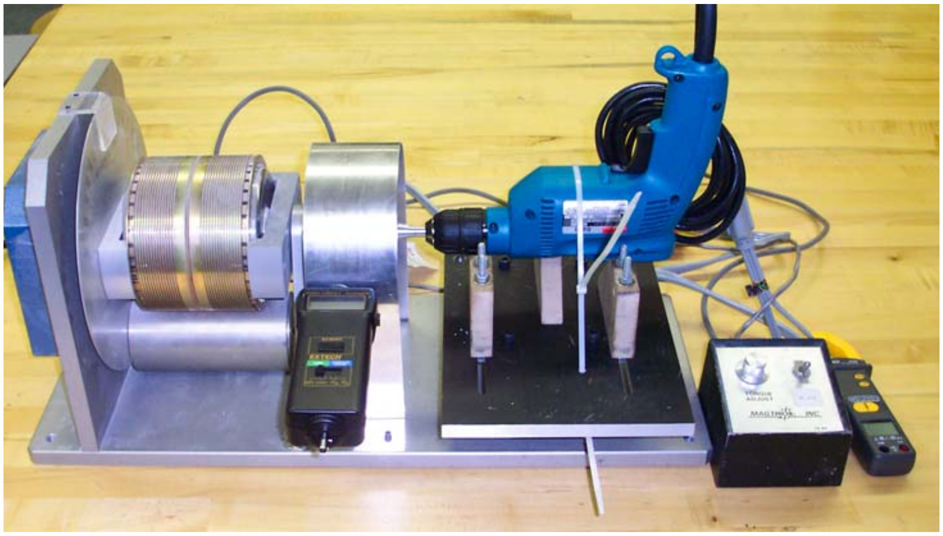


Figure 3. The performance of power drills is tested using a dial-weight dynamometer and optical tachometer.

3.2b Major Design Project

In the last half of the semester, student teams are tasked with a hands-on design project. This project provides motivation and context for learning the design process. This project requires the production of a working prototype and professional documents (proposal, detailed design report, final report). The ideal project should provide experience at all phases of the design process (Planning, Concept Development, System Level Design, Detail Design, Test and Refine and Production). The selection of a suitable project is always a challenge, generating considerable instructor debates. Some instructors prefer mechanical design projects such as might be found in the Shigley component design textbook [12], or from a design competition. These are narrowly scoped and easily judged, such as the design of a pump, or a water-powered vehicle (the current ASME design competition [13]). In these projects, the problem is already defined, and there is no contact between the designer and a real customer. Other instructors argue for a broader view of design in the context of a consumer product. Such a project would encompass problem definition, assessment of customer needs, aesthetics, ergonomics, and economics in addition to technical performance. The disadvantages of broader projects are that they take longer to complete, they can be so open-ended as to be frustrating to students, and they are more challenging for the instructor to grade.

Every project is a compromise between a <u>real</u> open-ended design problem as might be faced in industry, and a “<u>realistic</u>” surrogate which must conform to the limitations of an academic setting. Formulating a project which balances these conflicting views and can be reasonably completed in less than one semester is a daunting challenge. The ideal project has the following attributes:

1. Has an identifiable customer whose needs must be determined
2. Is interesting to students and addresses a real, compelling social need. A competitive element is desirable.
3. Allows for some creativity and self-exploration, but not so open-ended as to be frustrating

4. Requires attention to aesthetics, ergonomics, and economics
5. Requires students to apply knowledge from other ME courses (including Fluid Mechanics and Mechanical Component Design)
6. Involves energy in multiple forms (electrical, mechanical, and fluid)
7. Can fit in a shoebox for ease of transport and storage
8. Does not make a mess, or is easily contained and cleaned up
9. Safety (no 110V, etc)
10. Different each semester to discourage tribal knowledge
11. Able to be prototyped by the students with available materials and manufacturing facilities
12. $50 budget per team

Four projects have been developed to meet as many of the ideal characteristics as possible. These projects are cycled through each semester, on a two year rotation. The problem statements are listed below.

Faucet Powered Generator – Your company specializes in water turbines for micro-hydropower systems of 100 KW or less for homeowners, farmers and ranchers. The marketing department anticipates a new sales opportunity for a consumer product which can attach to a home faucet or shower head and produce electrical power, while the water is used for other purposes. Your team has been given the task to design a product intended for mass production, a project management plan, an economic justification and a demonstration prototype. The product should be inexpensive, attractive, easy to use, and efficient. You are also asked to propose an accessory/option for this product that will make creative use of the electrical power produced. You are not required to fabricate this accessory. One student team design is shown in Figure 4.

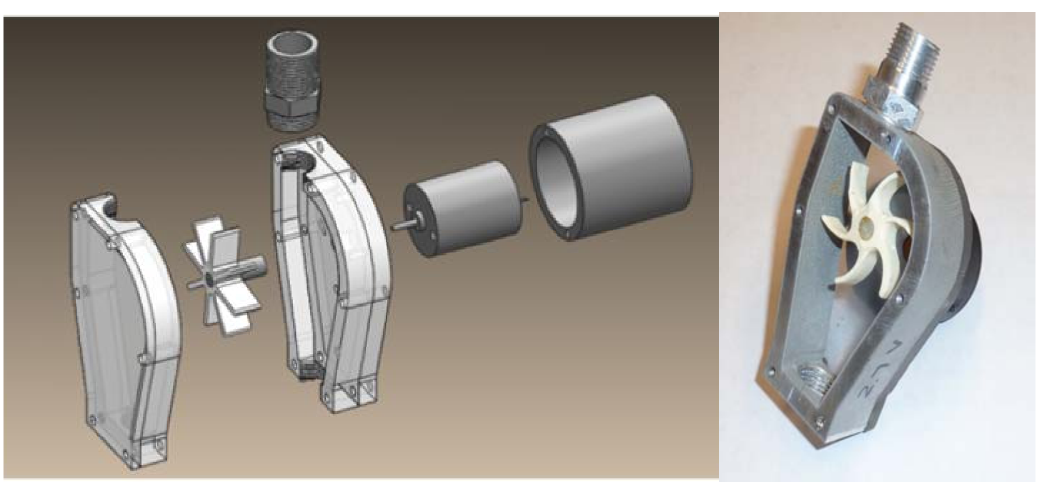


Figure 4. An example of a student-designed faucet-powered electrical generator, exploded CAD view on left, final machined prototype on right.

Solar-Powered Micro-pump – In many countries around the world, water is a scarce resource and must often be pumped or carried by hand. Traditional irrigation by flooding is very wasteful of water and highly labor intensive. A large fraction of these countries are located in geographical regions where sunlight can be a significant source of energy. Your company’s mission is to design a solar powered mini-pump system applicable to drip irrigation of crops. A PV solar array panel will be provided by another company with which your team has partnered for this project. Your team’s challenge is to design and test a full scale version of such a system. The design target is a minimum flowrate of 1.89 liters/min (0.5 gallon per minute) at a total head of 0.5 meter (19.7“).

Cordless Vacuum – ACME Tool Company has a product family of 18V cordless drills, saws, and sanders that have been very successful in the consumer market. Their marketing department recommends expanding the product line to include a cordless handheld vacuum. ACME routinely outsources their engineering work to the lowest bidder.   The product will be produced in their factory in Shanghai. They have invited several product development firms from around the world (including your company) to compete in the design and construction of a demonstration prototype.   The product will be evaluated by a jury consisting of corporate executives, typical customers, and investors based on its economic potential, aesthetics, ergonomics, and performance.   The winning firm will be awarded a lucrative contract. One student team design is shown in Figure 5.

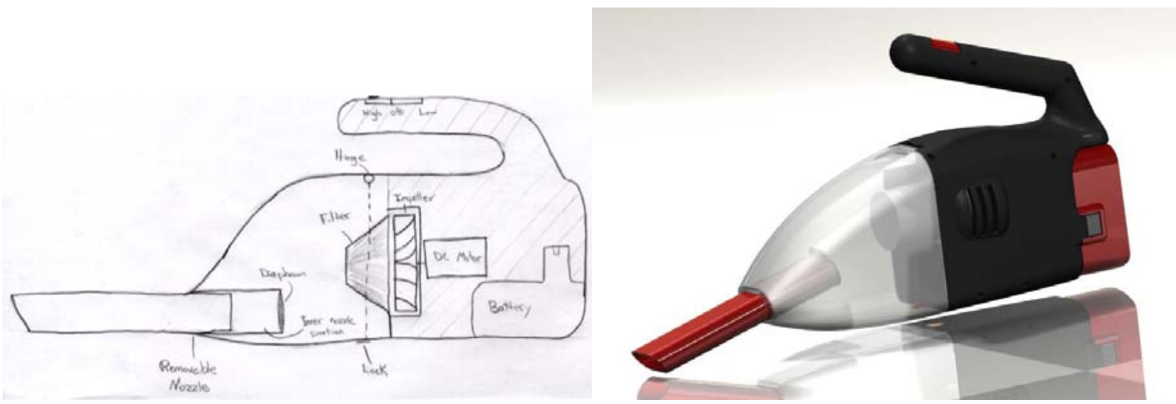


Figure 5. The evolution of a student-designed cordless vacuum cleaner from early concept sketch, to final design.

Micro Wind Turbine – Wind is attracting considerable attention as a source of renewable energy. Your team is asked to design, construct, and test a table-top windmill kit to educate and excite elementary school children in the basics of wind power generation. Your kit must be easily assembled and disassembled repeatedly by children 10 years of age or older.

3.3 Developing Team Skills

Except for quizzes and tests, most of the activities are executed in teams and receive a team grade.   Each individual is expected to participate fully and equally in all team activities. Three or four person teams are employed, with three being preferred. For an early team experience with neophyte designers, three seems to be the optimal number from our experience. A three person team guarantees a majority decision, provides enough diversity of skills to accomplish a task with a reasonable division of labor, and usually generates enough team problems to learn from without being too frustrating. Larger teams are more difficult for beginners to manage and are easier for someone to hide in.

A variety of approaches to team selection have been tried. These include forming teams to maximize diversity of personality types [14], maximize diversity of skills (leadership, CAD, shop practice), self-selection, and totally random. Students complete an online self-assessment of skills, commitment and schedule using the Team Maker utility of CATME[15]. The system allows the instructor to deliver initial demographic surveys to students and use the information gathered to create more optimal team assignments for class projects based on information such as race, gender, schedule availability, and many other factors. The instructor can choose the factors and their priority that are used in team selection. In the authors' experience, the most important factor is for students to have compatible schedules that allow for out-of class meetings. Of secondary importance are possessing a wide diversity of skills, and having a similar level of commitment.

Students are required to draw up a team contract that deals with items such as: mission, expectations, decision-making process, meeting guidelines, conflict resolution (including how to fire a team member), and member roles. Examples of previous contracts are provided on which to build. The very act of writing a team contract forces students to think about potential problems and their consequences. The contract is their first line of defense and helps them deal with many problems internally. Since we have instituted the contract, team problems requiring instructor intervention seem to have decreased.

It is critical to quickly identify team problems which might adversely impact the team's performance and which might require instructor intervention. However, students are extremely hesitant to report team problems to the instructor because they do not want to get their peers "in-trouble". The team situation must usually be very bad before students will break the "code-of-silence". Fortunately, students of the Facebook generation seem to be more forthcoming when it comes to electronic media. Online team checkups are done periodically throughout the semester using the CATME system. These checkups have been successful at identifying some potential team problems early in the semester. At the end of the semester, each individual completes a peer evaluation of their team members which is worth 10% of the final grade. In the final peer evaluation, students (individually and confidentially) are asked to distribute a fixed number of points (or a mythical dollar bonus), among their team members.

3.4 Instructor Expectations of Students

The major student complaints about this course are the high workload, and the high standards expected for course deliverables. Design is by nature a time-intensive activity. Consistent with University guidelines, this course requires 8-10 hours per week of individual effort, outside of scheduled class times. Until this point in their academic careers, students have not taken a course which truly requires this much effort, and a bit of re-education is required. Students are required to follow professional standards of behavior and attendance. Although they have already taken technical writing taught by the English Department, this is their first course which requires extensive writing within their major. We provide coaching, and try to convince them that effective writing is not just an academic exercise, but an essential skill that will directly correlate to their future success in the workplace.

3.5 Faculty Interaction

A unique feature of this course is the interaction among faculty members teaching parallel sections. In a typical semester, six sections are offered, requiring 4-6 instructors. To avoid faculty burn-out and to encourage new ideas, experienced faculty rotate out and new instructors are continually being rotated in. Weekly meetings are held to share teaching methods, divide up workload, and to make course changes. Instructors are encouraged, but not required to have common course deliverables and work expectations. These meetings are a proactive way of achieving consensus and promoting collegiality. They are also an efficient use of time and prevent "reinvention of the wheel". Prior to its first offering in 2006, a 3 day summer workshop was held to train faculty in how to teach this course and to collaboratively develop and refine the course content.

Instructors come from all branches of mechanical engineering, (mechanical, thermal-fluids, and nuclear). This diversity allows individuals to share their design experience to raise the collective expertise of the team. We do not all have to be experts in every aspect of the course. Over the years as the result of contributions from many instructors, an electronic library of course materials has been developed. The library includes lecture materials, classroom activities, videos, case studies, quizzes, exams, team building activities, and reference handouts. This library lessens the anxiety and dramatically accelerates the learning curve for new course instructors. Instructors are encouraged to contribute to the course legacy by developing new instructional materials and documenting them so that they can be used by others.

3.6 Logistical Issues

The major challenge of this course is to offer a quality educational experience to large numbers of students (>300 per year). Six sections are offered each semester with a section size limit of 30 students. The course is delivered in a specially designed, multi-purpose room that allows for both lecture, and hands-on project activities. Outside of class time, students make extensive use of computer labs for their CAD work, and the college machine shop (Learning Factory) for their prototyping tasks. A perennial problem that still has not been adequately solved is providing space where students can store their projects in-process. The course budget for equipment and supplies is $10,000 per year, and comes from student laboratory fees.

IV. Results

4.1 Assessment Tools

Formative and summative assessment tools were used to gather student feedback for continuous improvement of course content and delivery. Four assessment tools were used:

a. Best/Worst Design Essays
b. Ranking of 23 Design Activities
c. Design Survey
d. Student Self-assessment of course outcomes

4.1a Best/Worst Design Essays

At the beginning of the semester and then at the end of the semester, students were asked to write in their journal about a best and worst engineering design that they have observed. The assignment was given as:

> *Describe a recently introduced product that you think is well-designed and has some positive social value (or is poorly designed). Explain your reasoning in 1-2 paragraphs. A sketch or photo is recommended.*

At the end of the semester, these essays were photo-copied from the student journals for assessment. Two instructors read each essay and counted the number of design attributes that were mentioned in each essay. Design attributes included: ease of use, ease of handling/ergonomic, creativity/novel, versatility, meets customer needs, optional/enhanced features, manufacturability, durability, reliability, cost, appearance, ease of maintenance, and sustainability. If the two instructors did not agree on the count, they discussed the essay and reached consensus. The number of attributes described in the first essay at the beginning of the semester and the second essay at the end of the semester were compared to determine changes.

4.1b Ranking of 23 Design Activities

Atman et al.[16] describe a tool to assess students' understanding of engineering design. This assessment asks students to mark which six activities in engineering design are most important: abstracting, brainstorming, building, communicating, decomposing, evaluating, generating alternatives, goal setting, identifying constraints, imagining, iterating, making decisions, making tradeoffs, modeling, planning, prototyping, seeking info, sketching, synthesizing, testing, understand problem, using creativity, and visualizing. A list of the 23 attributes was given to the students in class and each student was asked to choose the six attributes that are most important in engineering design. The activity was then collected and the results were summarized by the percentage of students who select each response. These results were then compared to results from a group of seventeen experts as reported by Atman et al. In Fall 2010, the ranking of design activities was done at the end of the intermediate design course. In the future, we plan to conduct this activity at the beginning and end of the course and assess differences in students' responses.

4.1c Design Survey

The self-efficacy design survey developed by Carberry et al.[17] was used to measure students' self-concepts towards engineering design. Students are asked to evaluate their confidence, motivation, success, and anxiety in performing nine different design tasks. The question stem directions state: "Rate your degree of confidence/motivation/success/anxiety in performing the following tasks by recording a number from 0 to 100." The tasks listed under each stem are: conduct engineering design, identify a design need, research a design need, develop design solutions, select the best possible design, construct a prototype, evaluate and test a design, communicate a design, and redesign. In Fall 2010, the self-efficacy design survey was given at the end of the semester in one section of the junior design course. Ideally, the same quiz would be given to the class at the beginning and at the end of the semester to assess any changes in the students' responses. Since this assessment was started during the semester, a pretest was not possible and a control group was used instead. As a control group, the same survey was given to students in a junior-level class of Nuclear Engineering, Analytical Techniques in Nuclear

Engineering, who had not taken the junior-level design course. In the future, we plan to deliver the survey at the beginning and end of the junior-level design course and link the before and after responses of individual students.

4.1d Student Self-Assessment of Course Outcomes

As a fourth course assessment, students in the Design Methodology course were asked to rate their personal improvement in the fourteen course outcomes identified by the caucus of course instructors. The fourteen course outcomes were:

1. Formulate a design problem by translating customer needs into design objectives and constraints (including QFD and other tools)
2. Construct and modify a Gantt chart using MS Project and use it to plan and execute a project
3. Function effectively in a team environment; and can identify, assess and resolve team problems
4. Generate multiple design concepts and select and refine the best design concept using appropriate qualitative and quantitative techniques, (including brainstorming, decision matrix, and economic analysis)
5. Produce professional-quality reports, oral presentations, web pages, and graphical illustrations (using Solidworks) for design communication and documentation purposes
6. Access multiple sources of design information, including patents, previous courses, catalog data, reverse engineering, web search, consumer focus groups, empirical tests, etc
7. Demonstrate professionalism and ethical conduct
8. Assess the ergonomics and aesthetics of a design
9. Identify the environmental, safety and societal implications of a design
10. Assess the manufacturability and assembly of a product and suggest improvements
11. Communicate effectively using oral presentations and written reports to varied audiences
12. Model and analyze design solutions and correlate to actual performance
13. Produce physical prototypes
14. Find and learn new material on your own

For each course outcome, students were asked to rate the level of personal improvement using the following scale:

1= No Improvement
2= Slight Improvement
3= Moderate Improvement
4= Large Improvement

4.2 Assessment Results

Three course assessment tools (tools a, b, and c) were implemented in one section of the junior-level design course in Fall 2010. Assessment tool c was implemented in Spring 2010. Students in a Nuclear Engineering class (course title: Analytical Techniques in Nuclear Engineering) also completed the self-efficacy design survey (tool c) as a control group. A summary of the results in included in this section.

4.2a Best/Worst Design Essays

The number of design attributes described in the essay at the beginning of the semester was compared to the number described in the essay at the end of the semester. The results are shown in Table 4. If the number of attributes described in the two essays was the same or within one, it was considered no change. An increase or decrease in the number of attributes of two or more was considered significant. It was found that 9 students showed significant improvement (2 or more points improvement), 7 showed no significant change (0 or +/-1 point difference) and 3 had a change of -2 or more points

Table 4. Coded results of Good/Bad Design Essays (n=19)

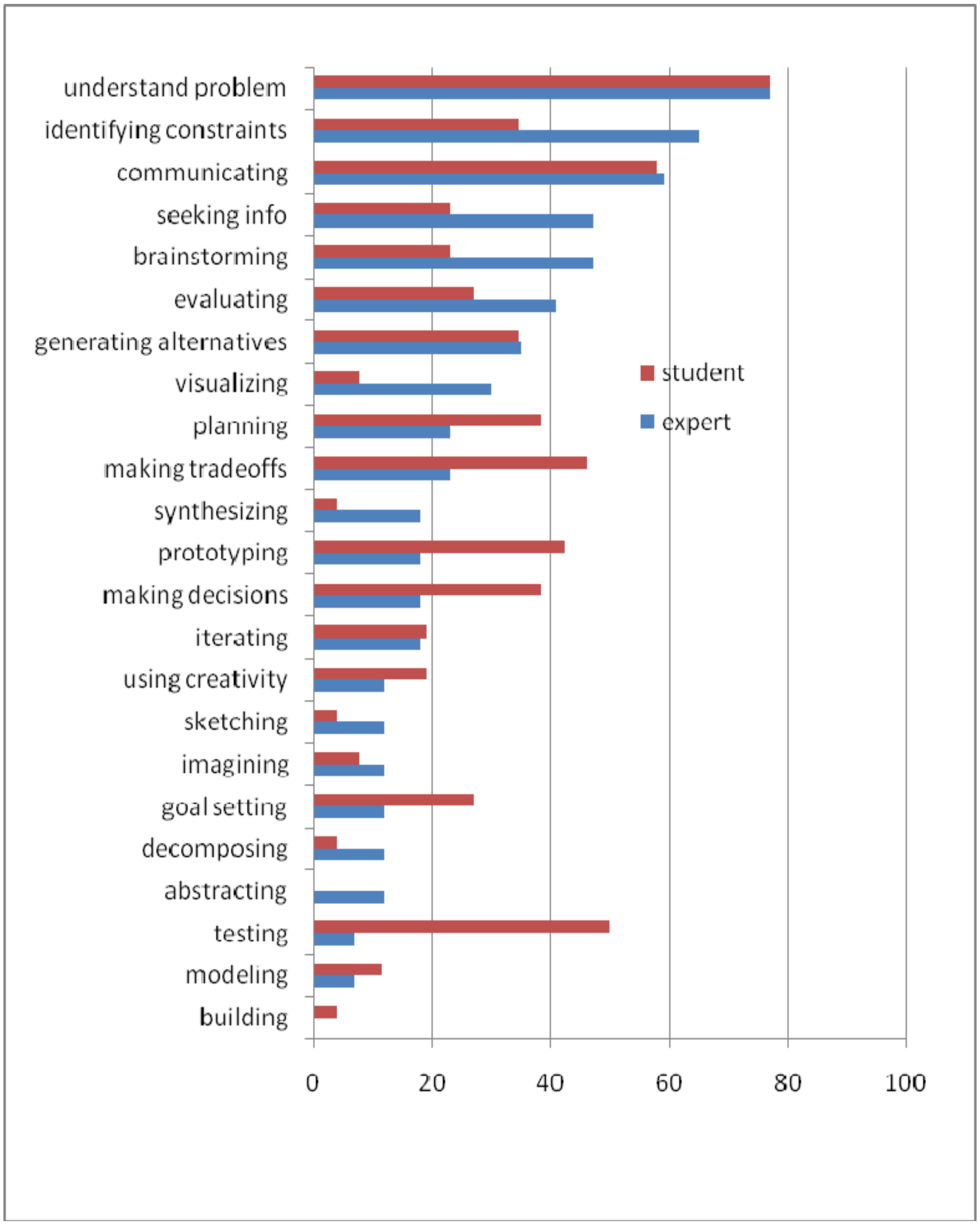
Category	Judging Criteria	Number of students	Average number of attributes at beginning of semester	Average number of attributes at end of semester
Significant improvement	+2 difference	9	3.2	6.4
No Significant Change	+/- 1 difference	7	4.4	4.4
Negative improvement	-2 difference	3	7.7	3

Three times as many students had an increase in attributes compared to a decrease. This was considered as a positive indicator. In the future, we plan to conduct this assessment in more sections of the intermediate design course. Although this assessment might be considered subjective, it is noted that the two instructors easily reached agreement in the number of design attributes that were included in the essay. This indicates some reliability in the assessment method.

4.2b Ranking of 23 Design Activities

Results of the design activities ranking activity are shown in Figure 6. The design activities are ordered using the experts' ratings. The activities of "understand the problem", "communicating", and generating alternatives ranked similarly high for both the experts and students. The experts, however, ranked "identifying constraints", "seeking information", "brainstorming", and "evaluating" as among the top six activities but the students did not. It is speculated that this is due to the design experience in the course where the design project was rather well-defined and the constraints were given. Students ranked prototyping and testing much higher than the experts. This again may be due to the design project assigned where several weeks were dedicated to building and testing a prototype. In comparison to the first year and 4th year students documented by Atman et al.[16], the 3rd year students in this survey ranked somewhere in-between.

Figure 6. Results of Design Activities Ratings. Expert results from Atman et al.[16].



4.2c Design Self-Efficacy Survey

Results from the Design Self-Efficacy Survey by Carberry et al.[17] are shown in Tables 5 and 6 for the two classes participating. For each stem (confidence, motivation, success, anxiety) and design activity (conduct engineering design, identify need,etc.) a mean was calculated. There were 27 students in the junior-level design course who took the survey and 88 students in the Nuclear Engineering junior-level course that took the survey.

Table 5. Design Survey Results for Students in the Junior-level Design Course. The highest and lowest averages in each question stem are highlighted.

	Question Stem			
Design Tasks:	Confidence	Motivation	Success	Anxiety
Conduct engineering design	71	71	73	46
Identify a design need	84	71	80	36
Research a design need	81	63	74	41
Develop design solutions	81	82	77	40
Select the best possible design	72	79	73	49
Construct a prototype	70	73	67	47
Evaluate and test a design	72	72	72	48
Communicate a design	75	67	70	51
Redesign	78	74	76	42
AVERAGE	76.0	72.4	73.6	44.4
Difference between min/max	14	19	13	

Table 6. Design Survey Results for Students in the Nuclear Engineering Junior-level Course (Control Group). The highest and lowest averages in each question stem are highlighted.

	Question Stem			
Design Tasks:	Confidence	Motivation	Success	Anxiety
Conduct engineering design	80	85	80	63
Identify a design need	86	86	85	53
Research a design need	86	76	82	55
Develop design solutions	80	87	82	62
Select the best possible design	86	95	86	56
Construct a prototype	74	89	78	65
Evaluate and test a design	80	89	83	59
Communicate a design	89	85	85	60
Redesign	83	78	79	58
AVERAGE	82.7	85.6	82.2	59
Difference between min/max	15	19	8	

The results can be examined for a given question stem (confidence/motivation/success/anxiety), for a given design task (across a horizontal row), and between the two classes (between Tables 5 and 6.) In the first 3 questions stems (confidence, motivation, success) a high score is associated with a more positive outcome. However, in the anxiety category, a low score is the most desired outcome. From the responses, however, it appears that some students may have misunderstood the question (for example giving similar ratings for confidence and anxiety). This moved the anxiety average closer to 50%. Due to apparent misunderstandings of students completing the survey, the anxiety data will not be analyzed.

In looking at the responses for a given question stem (confidence, motivation, and success columns) the lowest and highest average ratings have been highlighted and the difference between these values listed as the last row of the table. Both the design class and control class had lowest confidence in constructing a prototype. In both the design class and control class, students indicated the least motivation for *research a design need*. Both classes predicted the lowest success in *constructing a prototype*. The difference between the minimum and maximum rating in a question stem was similar for both the design class and the control class. The range of ratings was smallest in the motivation question stem. Although the range of ratings in a particular stem varied by 19 at most, the ratings from an individual student often varied more significantly. For example, under the confidence stem (first column of ratings), some students gave ratings from 40 to 100 for the nine different design activities. But the design task that was rated low was not the same for each student and the average ratings for the class showed a smaller range.

In looking at the responses for a given question stem (confidence, motivation, and success columns) it is found that the Nuclear Engineering control group had higher averages than the design class. There is a significant difference between the ratings in the Mechanical Engineering junior-level design course and the control course (Nuclear Engineering junior-level lecture). Unexpectedly, the ratings in the control course are significantly higher. (The anxiety ratings are again suspect and are not included in these generalities.) We are not sure what conclusions to draw from this. It is possible that a student can not accurately access his/her design skills before they are exercised in the junior-level design course. The students' naiveté may be reflected in higher ratings before attempting a design project with prototype building. Or it is possible that the students in the control group did not carefully consider the questions since the activity was given for extra credit and was not part of the course. The survey was given electronically to the students in the Nuclear Engineering course and the average time to take the survey was 18 minutes. This seems adequate for a careful consideration of the survey questions. Further analysis will be done to review the times that individual student took to complete the survey and relate this to survey results.

4.2d Student Self-Assessment of Course Outcomes

In the Spring 2010 semester, students in one section of the Design Methodology class were asked to self-assess their personal improvement in the fourteen course outcomes. The results are summarized below in Table 7. For each course outcome, the number of students giving each response is tabulated. A mean and standard deviation is then calculated for each outcome. In Table 7, the outcomes are ordered from highest mean score to lowest mean score. For reference with the full outcome description, the number before each course outcome indicates the outcome number as listed in section 4.1d. Seven of the fourteen course outcomes show a mean rating of 3.0 and above, indicating moderate to high improvement in student proficiency. The ratings correlate well with the amount of class time spent on these topics, and identify potential areas for course improvement.

Table 7. Results of Student Self-Assessment of Improvement in Course Outcomes

	Number of students					
Course Outcome	**no (1)**	**slight (2)**	**moderate (3)**	**large (4)**	**mean**	**stdev**
13. Produce physical prototypes	0	3	9	17	3.48	0.688
4. Generate multiple design concepts	0	2	14	13	3.38	0.622
3. Function effectively in teams	0	4	15	10	3.21	0.675
6. Access multiple sources of information	0	4	15	10	3.21	0.675
1. Formulate design problems	1	4	13	11	3.17	0.805
5. Produce professional reports	1	4	14	10	3.14	0.789
10. Design for Assembly/Mfg	1	6	12	10	3.07	0.842
11. Effective communication	0	9	13	7	2.93	0.753
12. Model and analyze solutions	0	7	18	4	2.90	0.618
14. Find and learn new material on own	2	7	12	8	2.90	0.900
7. Professionalism and ethical conduct	1	9	12	7	2.86	0.833
2. Construct and modify Gantt Chart	2	13	7	7	2.66	0.936
8. Assess ergonomics and aesthetics	3	10	11	5	2.62	0.903
9. Identify environmental safety and societal implications	2	17	9	1	2.31	0.660

4.3 Summary of Assessment Results

Two assessment methods, the Best/Worst Design Essays (Section 4.2a) and the Student Self-Assessment of Improvement in Course Outcomes (4.2d) have shown that the Design Methodology course has improved the students' ability to complete design tasks. The results from the Ranking of 23 Design Activities (4.2b) and the Design Self-Efficacy Survey (4.2c) did not conclusively show that the Design Methodology course improved students' ability to complete design tasks. In the future, these assessment tools will be refined and used in several sections of the Design Methodology course to determine any difference between sections. In addition, the Ranking of 23 Design Activities (4.2b) and the Design Self-Efficacy Survey (4.2c) will be used at the beginning and end of the course to assess changes in students understanding of the design process and confidence, motivation, and expected success in design tasks.

V. Conclusions

The major challenge of this course is to offer a high-quality design experience to over 300 students per year in multiple sections with multiple instructors. After 5 years of operation, the course has achieved its objectives and was singled out for special recognition in our latest ABET review. The student "word on the street" is that the course is a lot of work, but they learn a lot. Assessment results show that students who have taken this course are more confident in their abilities to manage and complete an open-ended design project involving multiple trade-offs. There has also been a noticeable improvement in student performance in the capstone design course. Due to this success, the Electrical Engineering Department is instituting a similar course tailored to the needs of their students. The Nuclear Engineering program recently added this course to their degree requirements. With continuous input from faculty and students, the course continues to evolve and improve.

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