ME Curriculum Redesign Through an Assessment Process

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Abstract

The curriculum at the Department of Mechanical Engineering at IUPUI was redesigned, addressing the ABET 2000 outcomes through a systematic assessment process. Systematic use of the assessment tools for a period of four semesters revealed certain shortcomings in the programs. The changes made to our curriculum address the identified shortcomings. The new curriculum was introduced in Fall 2003 and includes a thermal-fluid systems design course, a seminar component in the capstone design course, a statistics and probability elective, and general education electives better reflecting the cultural and societal outcomes of ABET EAC 2000. We believe that the new B.S.M.E. curriculum better prepares our engineering graduates to readily enter the work force in the 21st century.

Introduction

The mission of the Department of Mechanical Engineering at IUPUI is to provide high quality education in mechanical engineering for both undergraduate and graduate students. The Mechanical Engineering B.S. Degree program at Indiana University–Purdue University Indianapolis (IUPUI) has been accredited by ABET since the early 1980s and is currently due for a review in Fall 2004. Recently, there has been a growing emphasis on redefining the curriculum based on an assessment of program outcomes that provide a strong balance of technical background and professional development.

Any curriculum redesign needs to include the Accreditation Board for Engineering and Technology (ABET) 2000 outcomes-based assessment [1]. Engineering educators have been modifying and enhancing the mechanical engineering curriculum through a variety of means including advanced breadth and depth, creative and collaborative process and multidisciplinary projects and experience [2-6]. Murphy and Lineberry [4] discussed the accreditation preparations at Paducah campus for a collaborative mechanical engineering program jointly with University of Kentucky. The emphasis for such collaborative program was on uniqueness and distinguishes from the main campus. The recommendations from the study emphasized the student population, demographics, faculty, and surveys related to assessment and graduates. Deng et al. [5] discussed the evaluation of assessment tools for outcome-based engineering courses for mechanical engineering program at Alabama A & M University. They adopted an approach based Bloom's taxonomy and is called SEAARK (Knowledge, Repetition, Application, Analysis, Evaluation and Synthesis) in reverse order. Specifically, they discussed the assessment evaluation for data on fluid mechanics course. Schmidt and Beaman [7] discussed a department-wide major curriculum reform effort, PROCEED, an acronym for Project-Centered Education.

Following ABET [1], each engineering department, the program outcomes are summarized as educational objectives that describe the unique characteristics of that program. Similar to other curriculum reform and programs [2-7], a major challenge in curriculum redesign is incorporation of adequate courses into the program that assess depth and breadth of knowledge of technical concepts, demonstration of thinking and problem solving skills, professionalism, awareness of cultural and societal issues and life-long learning. We have undertaken the challenge of defining our B.S.M.E. program's outcomes based on EAC 2000 criteria and went through several steps to develop an assessment process and redesigned the curriculum based on the findings through various surveys and faculty evaluation.

Program Educational Objectives and Outcomes

The program educational objectives were defined by considering the various significant constituencies of the mechanical engineering department consisting of 1) all ME students and faculty, 2) alumni, 3) industrial advisory board, 4) undergraduate student advisory board, 5) local chapters of student societies (ASME, AIAA, NSBE, SAE, SWE), 5) the School and University, and 6) potential employers.

The overall educational objective of the undergraduate program in the Department of Mechanical Engineering is to educate students with excellent technical capabilities in mechanical engineering discipline and related fields, who will be responsible citizens and continue their professional advancement through life-long learning. The Program Educational Objectives of the Department of Mechanical Engineering are to educate undergraduate students who – during the first few years following the graduation – will:

1. Demonstrate excellent technical capabilities in mechanical engineering and related fields
2. Be responsible citizens
3. Continue their professional advancement through life-long learning
4. Apply sound design methodology in multidisciplinary fields of mechanical engineering
5. Competently use mathematical methods, engineering analysis and computations, and measurement and instrumentation techniques
6. Practice effective oral and written communication skills
7. Understand the environmental, ethical, diversity, cultural, and contemporary aspects of their work
8. Work collaboratively and effectively in engineering or manufacturing industries

These program educational objectives have been set by the assessment and curriculum committees of the department in consultations with the faculty and feedback from students, industry and alumni. They are also related to the program outcomes outlined below.

Consistent with the criteria set by the Accreditation Board for Engineering and Technology (ABET), the Program Outcomes of the Department of Mechanical Engineering are to educate graduates who – by the time of graduation – will be able to:

- **a.** Demonstrate and apply knowledge of mathematics, science, and engineering with:
  - **a1.** Knowledge in chemistry and calculus-based physics in depth
  - **a2.** Mathematics through multivariate calculus, differential equations, and linear algebra
  - **a3.** Probability and statistics
  - **a4.** Mechanical engineering sciences: solid mechanics, fluid-thermal sciences, and material science
- **b.** Conduct experiments methodically, analyze data, and interpret results
- **c.** Design a system, component, or process to meet desired needs with applications to:
  - **c1.** Mechanical systems
  - **c2.** Thermal systems
- **d.** Function in teams to carry out multidisciplinary projects
- **e.** Identify, formulate, and solve engineering problems
- **f.** Understand professional and ethical responsibilities
- **g.** Communicate effectively in writing and orally
- **h.** Understand the impact of engineering solutions in a global and societal context through broad education
- **i.** Recognize the need to engage in lifelong learning
- **j.** Demonstrate knowledge of contemporary issues
- **k.** Use the techniques, skills, and modern tools of engineering effectively and correctly in engineering practice with:
  - **k1.** Mechanical engineering analysis tools (e.g., ANSYS, ProMechanica, etc.)
  - **k2.** Engineering design and manufacturing tools (e.g., AutoCAD, ProE, etc.)
  - **k3.** Internet and library information resources
  - **k4.** Mathematical computing and analysis tools (e.g., Matlab, Excel, Labview, etc.)

Even though these outcomes are same as those defined by ABET, the more general outcomes a, c, and k are further subdivided into sub-outcomes to emphasize the program strength we want to reach.

Development of the Assessment Process

Several individuals and committees assisted in the development of our assessment process: 1) The School Assessment Committee, 2) Departmental Assessment and Accreditation Committee, 3) Departmental Undergraduate Education Committee, 4) all course instructors, 5) the Industrial Advisory Board, and 6) the Undergraduate Student Advisory Board were involved in the assessment process. It was determined through a series of meetings that surveys would be useful tools in defining program outcomes, measuring student satisfaction and evaluating the quality of instruction in addition to the direct assessment methods utilized in individual courses. In the next few sections, the assessment tools used, the findings of the assessment process and the features of the new developed curriculum are discussed.

Assessment Tools

The assessment tools have been established in order to address the ABET outcomes a-k within a continuous program improvement process as shown in Figure 1. About 10-12 outcomes are identified by faculty for each course, which are related to program outcomes a-k, leading to a program matrix relating the course outcomes to program outcomes. This program matrix showed both strengths and weaknesses of the curriculum. The assessment tools are developed were based on extensive discussions with the School assessment committee along with various constituencies suitable for our program at IUPUI. The various assessment tools developed/used are listed below.

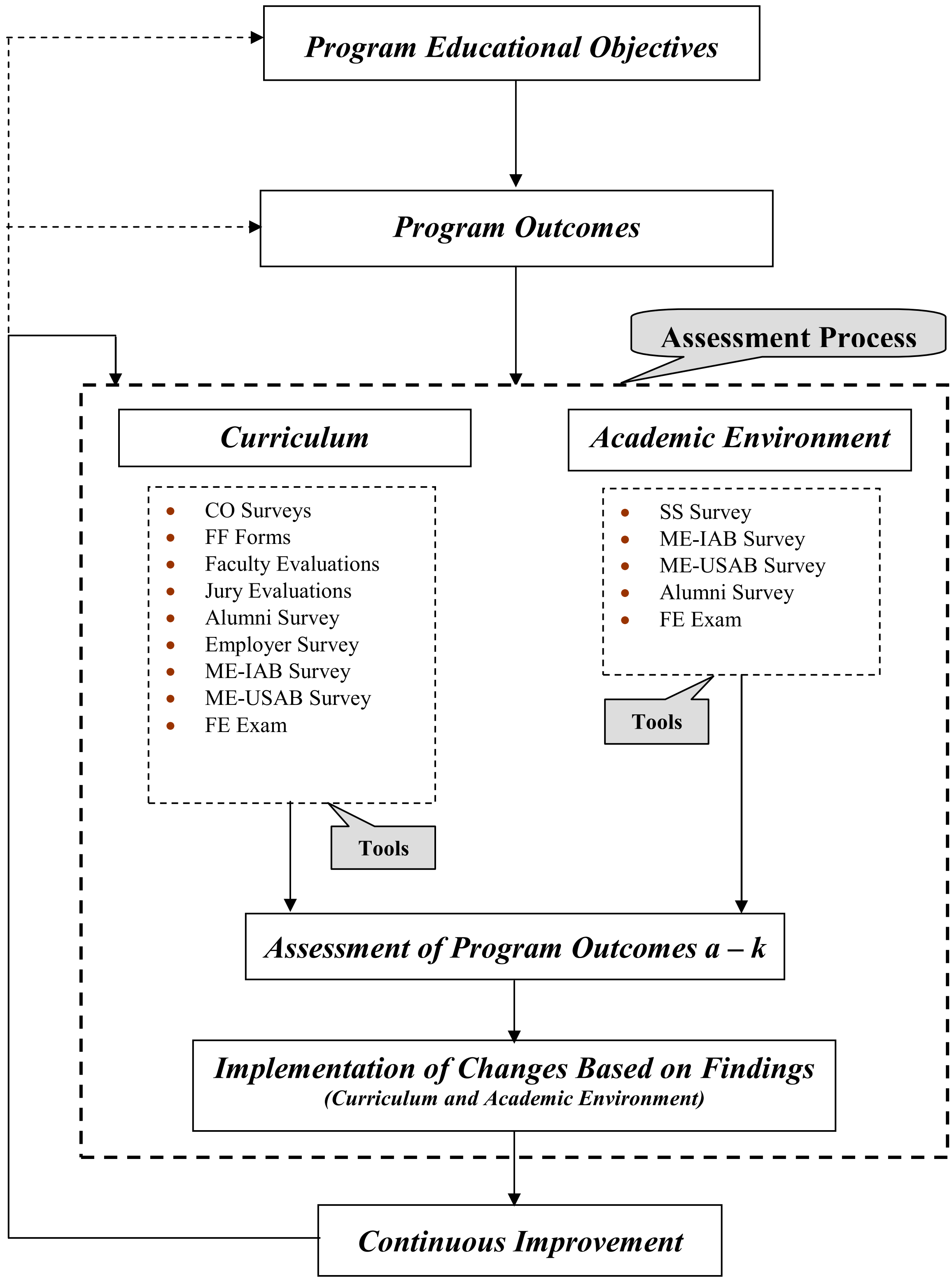
1. Course learning outcomes surveys in all courses (measuring the student satisfaction on meeting these outcomes)
2. Exit surveys given to graduating students on program outcomes (measuring student satisfaction on meeting outcomes)
3. Faculty feedback forms on course outcomes survey results
4. Student satisfaction via additional surveys and meetings
5. Alumni and employer surveys
6. Fundamentals of Engineering (FE) exam results
7. Common guidelines and rubrics for student reports in laboratory experiments and major design projects
8. Jury evaluation of student work in selected key courses which cover all program outcomes
9. Instructor's direct assessment of outcomes in exams and key projects
10. Documentation on the Web (http://www.engr.iupui.edu/me/fassessment.shtml), including exemplary student work

Findings from the Assessment Process

A systematic use of the above assessment tools for a period of four semesters revealed certain shortcomings in the programs. The shortcomings were found in the curriculum as well as delivery of student services. Curriculum deficiencies were found in the following areas: statistics, probability and data analysis; computer applications for design and analysis; thermal systems design; multidisciplinary applications; and general education (ABET outcomes: *h - understand the impact of engineering solutions in a global and societal context* and *j - demonstrate the knowledge of contemporary issues*). The deficiencies in the area of student services included inadequate advising and inadequate experimental labs. The above findings from the assessment are addressed by systematically reviewing the curriculum. The changes made to our curriculum, the details of which are discussed later.

Alumni Survey

An alumni survey was conducted in early 2003 asking the recent graduates (1993 - 2002) to rate their ability to meet the ABET criteria a-k in the work place and rate the importance of these outcomes. This survey indicated that the alumni rated their competency in skills and knowledge associated with program outcomes a3, b, h and j lower than all others. They rated the importance of outcomes h and j lower than the others.



Definition of Acronyms: 1) CO = Course Outcomes, 2) FF = Faculty Feedback, 3) IAB = Industrial Advisory Board, 4) USAB = Undergraduate Student Advisory Board, 5) FE = Fundamentals of Engineering, 6) Student Satisfaction.

Figure 1. Overview of the assessment process to redefine the curriculum.

Industrial Advisory Board Survey

In spring 2002, the Industrial Advisory Board was also asked to rate the importance of the program outcomes a-k in adopted by the program. This survey showed that the industry considered the importance of outcomes a2, a3, i, h, j, and k3 considerably lower than all others.

Changes Implemented

Two major changes were implemented in the area of student services. We established a new student advising process (the student is required to meet his/her advisor at least once a semester to discuss program plan of study, career goals, and any other academic support as needed and fill out an advising form). Various lab equipment and experiments are now being upgraded continuously. In addition, the standard formats and evaluation rubrics have been developed for laboratory and major project reports.

The changes implemented in the area of curriculum deficiencies based on the outcomes surveys include the following: a) introducing modern computer software (Matlab, Microsoft Project, ProE, Pro-Mechanica, Ideas, ANSYS) applications in design courses b) changes to capstone design course addressing professionalism, multidisciplinary applications, safety, societal and environmental aspects, c) introducing a thermal and fluid systems design course, d) addition of a statistics and probability course in the new curriculum, and e) choosing a set of general education electives that more directly address cultural and societal outcomes of ABET.

New Curriculum

The Assessment Committee monitored and evaluated the survey results and feedback received from different constituencies and made recommendations to the Undergraduate Curriculum Committee, which in turn proposed the changes to be approved by the entire department faculty. Figure 2 shows the new elements of the redesigned curriculum starting from freshman to senior years. At the freshman year, a new course, *ENGR 195 Introduction to Engineering Profession,* was introduced to make students aware of study habits, time management, engineering projects, and tools for technical writing and oral presentations. Engineering design examples along with specific tools were introduced in *ENGR 196 Introduction to Engineering*. Design and analysis tools (ProE, Matlab and C+ programming) were introduced in *ENGR 197 Introduction to Programming Concepts*.

At the sophomore level, the changes include a new course *ECE 204 Introduction to Electric and Electronic Circuits*, which emphasizes digital circuits in addition to analog circuits and the corresponding laboratory experiments. This course was designed by the ECE department to replace a linear circuits course and its laboratory. At the junior year, two courses *ME 340 Dynamics Systems and Measurements* and *ME 482 Control System Analysis and Design*, are jointly offered with the Electrical and Computer Engineering (ECE) Department, providing the students multidisciplinary team experience in projects and lab experiments. In addition, the *ME 340* was revised to reflect dynamic systems, system identification, measurements and simulation, LabView software integration, etc. In the *ME 482* course, a significant design project was introduced to demonstrate the control design aspects and involve student groups from both ME and ECE departments. These courses lays the foundation for an elective course titled

"Mechatronics" in the curriculum. Also, a statistics course was introduced dealing with probability, statistics and data analysis offered by the Math/ECE departments.

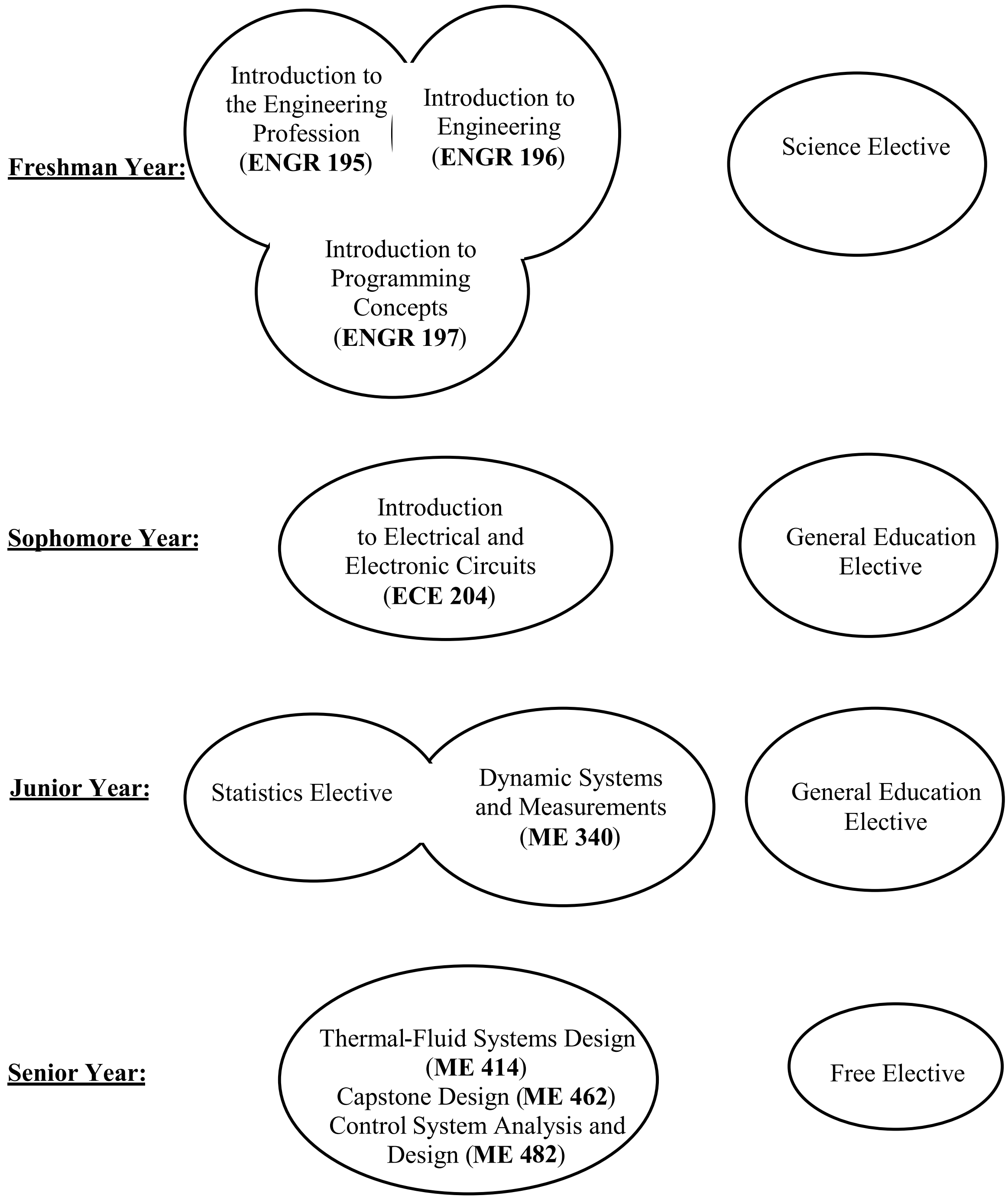


Figure 2. New elements of the redefined curriculum.

At the senior level, a new design course, *ME 414 Thermal-Fluid Systems* Design, was introduced to address the need for design of thermal-fluid systems. The first part of the course begins with a review of basic theories of fluid and thermal systems and the design process. The second part deals with the design practices associated with thermal-fluid systems, and involves the design of piping systems and heat exchangers. Finally, the application of optimization techniques (through Matlab software) for design is also introduced. In the capstone Design course (*ME 462*), a seminar component was added to address professionalism, project management, sustainability and safety and environmental aspects.

We recognize that the curriculum should include a strong general education component that provides students an integrated and well-rounded education in the humanities, social sciences, arts, and related areas. In addition to the 9 credit hours required in written communications (*ENG W131*), public speaking (*COMM R110*), technical communications (*TCM 360* with both written and oral components), a total of 15 credit hours for general education electives are required in the revised curriculum. One course, *ECON E201 Introduction to Microeconomics* (3 credits), is a required course that addresses contemporary microeconomic theories; market and price issues; method of economics; market, price, and resource issues. At least 6 credit hours of the remaining 12 credits must be chosen from those courses on the approved list of courses, which are indicated as having significant *contemporary*, *societal*, or *cultural* emphasis. This list has been prepared by conducting a campus-wide survey of all relevant courses offered by other departments/schools at IUPUI. The students will work with his/her academic advisor to select the general educational electives.

The overall program map of the courses in the new curriculum is shown in Figure 3 (see also http://www.engr.iupui.edu/me/bulletin/programmapfall2003.htm), where the courses are grouped into following units:

1. Freshman Engineering
2. Communications and Ethics
3. Engineering Design
4. Mechanical Sciences
5. Mathematics and Physical Sciences
6. Thermal-Fluid Sciences
7. ME Electives
8. Systems, measurements and Controls
9. Electives: a) general, b) science, and c) free

Design Across the Curriculum

Figure 4 shows the integration of design-oriented courses throughout the ME curriculum, starting from a freshman course dealing with the introduction of design based projects using ProE software, and progressing through sophomore and junior levels, and finally culminating with the capstone design experience at the senior level. The sophomore level design course (*ME 262 Mechanical Design I*) introduces the design process starting from customer requirements to conceptual design and presentation, and introduction to mechanisms analysis. The junior level design course (*ME 372 Mechanical Design II*) deals with the design of machine elements and their analysis, strength-based design along with specific experiments for fatigue, and creep and vibration. This course also has an experimental lab component. CAD/CAM software is utilized in both *ME 262* and *ME 372* for design and analysis of mechanisms and machine elements.

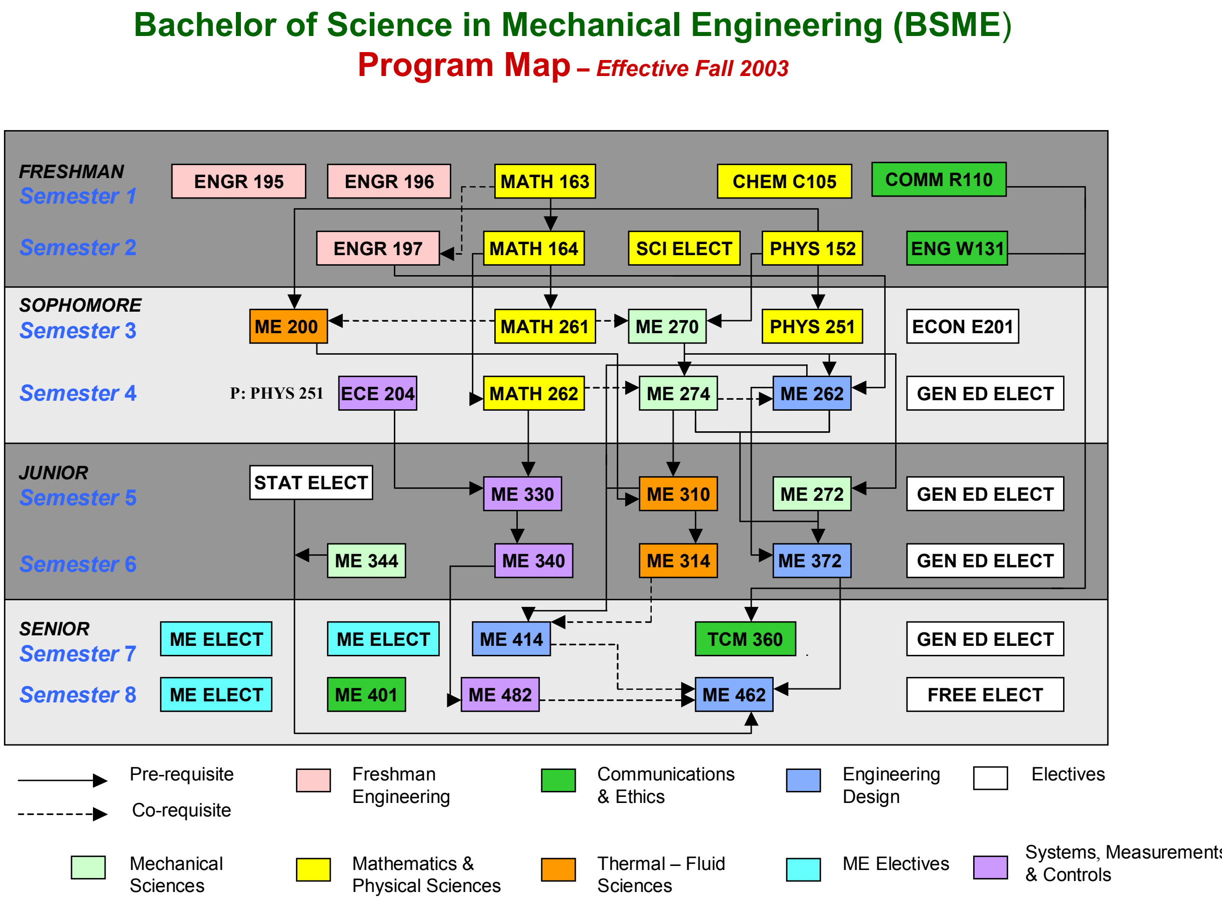


Figure 3. Program map of the new curriculum.

The capstone design course (*ME 462*) integrates what students learn in the rest of the curriculum and requires them to implement the design process by working on an independent project sponsored by industry or faculty. As it can be seen from Figure 5, the capstone design course implements the design process for an assigned project sponsored by industry or faculty. The students are required to discuss safety, environment, and societal impact of their designs in addition to ethics and professional responsibility. Recently, a seminar component was added to the course where guest speakers from industry and faculty from various disciplines are invited to speak about such topics as professionalism, project management, green design and manufacturability, sustainability of design, arts and bio-inspired designs, robust design, and specific design project experiences. As part of the course requirements, students in the capstone design project are required to write a brief report summarizing the seminar topics and discussing what they have learned. At the end of the course, student groups are required to demonstrate their design through a final formal presentation to the faculty, fellow students and a jury of industry guests and faculty from other departments. A design award is given to the best design each semester. During the senior year, students are made to understand and appreciate the importance of design, and recognize that many engineering problems are of a multidisciplinary nature and require teamwork and professionalism. These experiences encourage them to do their best once they are employed in industry.

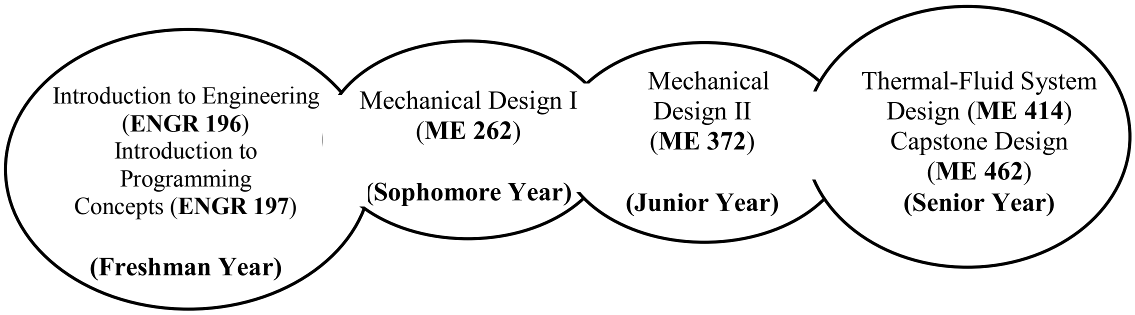


Figure 4. Design oriented courses throughout the redefined curriculum

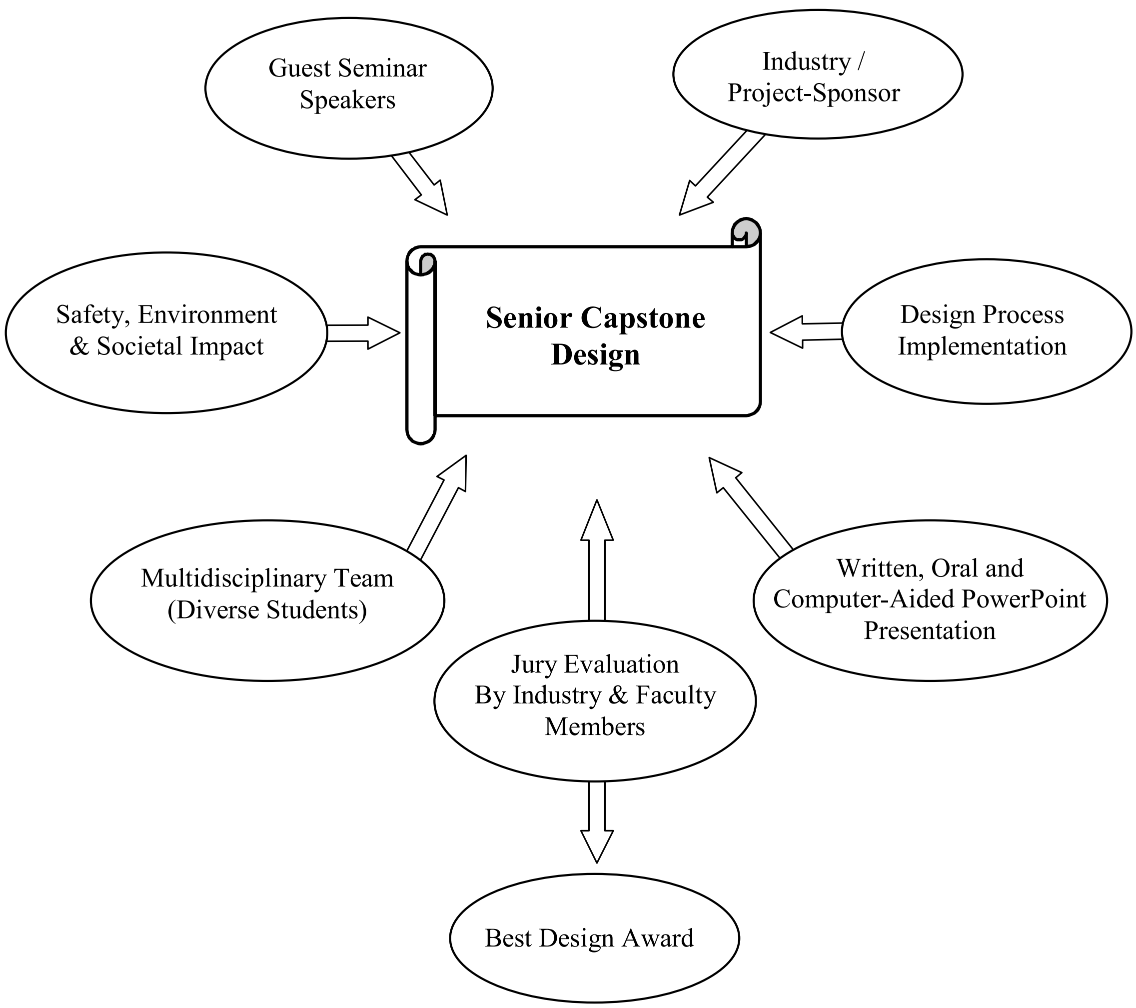


Figure 5. Overview of the capstone design course (ME 462) in the redefined curriculum.

Feedback From Advisory Boards

The overall assessment process adopted and the changes leading to the new curriculum were presented to the Industrial and Student Advisory Boards to receive feedback on continuous program improvement. Table 1 shows the feedback survey results from both boards. It can be seen from Table 1 that overall the assessment process and the new curriculum received favorable ratings. The lowest two ratings from the students were on: 1) the introduction of a new statistics and probability course in the curriculum, 2) policy adopted for general education electives. These indicate that we have not done a good job of convincing the importance of these two outcomes in their education – which we will have to work on. The policy adopted on general education electives was also rated the lowest by the Industrial Advisory Board, again indicating that perhaps we have not been able to articulate the new features of the policy adequately. It is also a reflection of the industry opinion that general education electives are perhaps not an essential part of engineering education – which is a rather limited view. We will continue to seek feedback from other constituencies of the ME program. We will monitor the impact of the changes in the curriculum using the assessment tools developed and maintain continuous quality improvement in our academic programs.

Evaluation of Assessment Tools

For the past two years, we have been using the assessment tools discussed earlier in majority of courses in order to meet the overall program objective and outcomes. In this section, *ME 414 Thermal-Fluid Systems Desig*n course will be discussed as an example. This course is designed to provide the student with basic working knowledge of fluid and thermal systems, and the design process. The course also deals with the open-ended problems in the design of piping systems and heat exchangers. An application of optimization techniques (through Matlab software) for design is also introduced in the course. The course outcomes are listed below. The items within brackets in the list indicate the specific ABET outcomes covered in this course.

1. Develop a sound understanding of thermal-fluid systems engineering design. [a4, c2]
2. Formulate, analyze and design thermal-fluid systems. [a4, c2]
3. Apply computer aided engineering principles to thermal design. [a4, c2, k1]
4. Apply optimization principles in design. [c2]
5. Design various piping fluid systems. [c2]
6. Design various heat transfer thermal systems. [c2]

The teaching methods used in this course include lecturing, home works, real-world examples, simulations, tests, and projects. The assessment tools used to evaluate the student learning of outcomes in this include combination of course outcomes surveys, home works, project reports, and jury assessment of projects through oral presentation. Assessment results for this course, which has been offered twice so far, are briefly discussed below.

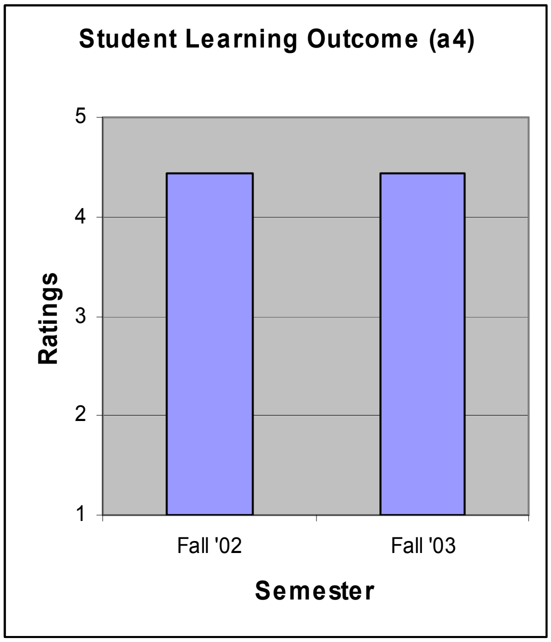
The student self-assessment results from the course outcomes survey are presented in Figure 6 for the past two years. It can be seen that both the outcomes in both the years exceed the department's threshold of 3.75. Overall, the student self-assessment of course outcomes indicates that the students should be able to design thermal-fluid systems. Figure 7 shows the two-year results of jury assessment of *ME 414* course projects, specifically the aspects of creativity and the use of engineering principles, and the effectiveness of written and oral presentation skills. It can be seen from Figure 8 that from Fall 2002 to Fall 2003, there is a slight increase in written/oral presentation skills where as the use of engineering principles and creativity decreased slightly. This may be due all the student groups are doing the same design projects. Overall the results presented in Figures 6 and 7 indicate that the assessment tools adopted do provide good information for continuous improvement of program outcomes.

Also, overall assessment process adopted and the changes leading to the new curriculum were presented to the Industrial and Student Advisory Boards to receive feedback on continuous program improvement. Table 1 shows the feedback survey results from both boards.

Table 1. Results of survey of Industrial and Student Advisory Boards on the ME program assessment methods and curriculum changes.

(on a scale of 1 – 5; 1 – very unsatisfied, 5 – very satisfied)

Item	Industrial Advisory Board Assessment	Student Advisory Board Assessment
Vision statement	4.25	4.44
Mission statement	4.38	4.67
Program objectives	4.75	4.44
Program outcomes	4.75	4.44
New statistics and probability course	4.63	3.89
New fluid-thermal systems design course, ME 414	4.38	4.56
Changes made in the capstone design course, ME 462	4.25	4.63
Policy adopted for general education electives	4.00	4.11
Department's Assessment Web site (http://www.engr.iupui.edu/me/fassessment.shtml)	4.50	4.33
Overall program assessment methods	4.63	4.67
Overall planned curriculum changes	4.38	4.56
Overall	4.45	4.43



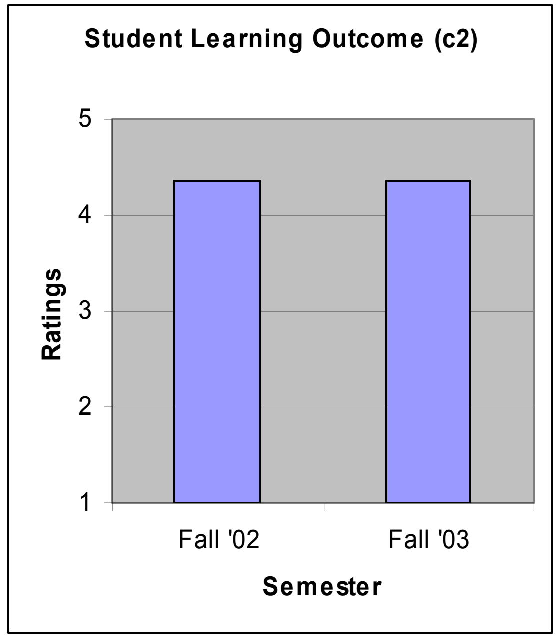
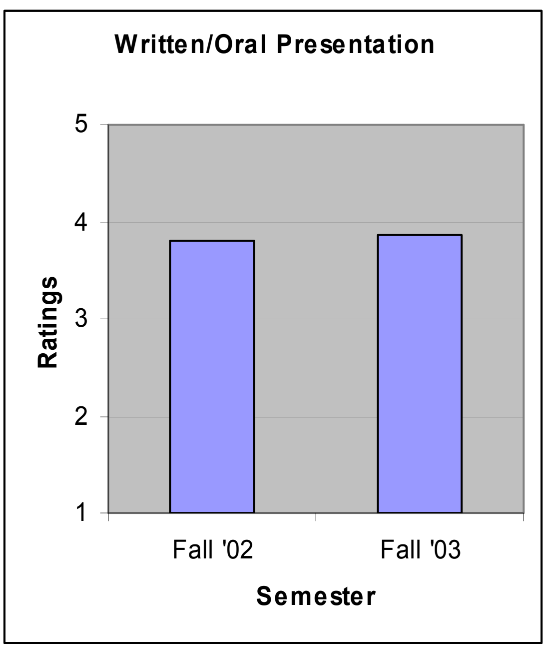


Figure 6. Student self-assessment of Program Outcomes (a4, c2) in ME 414 course for the past two years.



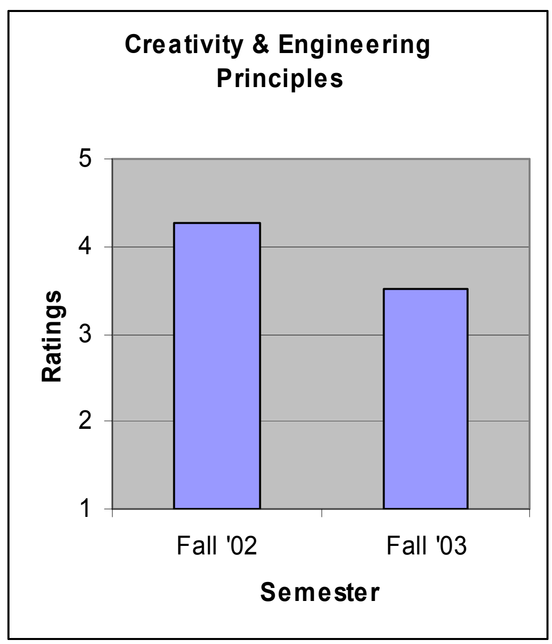


Figure 7. Jury Evaluation results for communication, creativity, and use of engineering principles in ME 414 course for the past two years.

What Did We Gain?

The following are the benefits we gained through a systematic approach, addressing the ABET outcomes based assessment.

- A systematic approach for evaluating and detecting the strengths and weaknesses of the program
- A systematic feedback method for making changes
- A systematic methodology for promoting and maintaining quality
- More attention given to specific outcomes in the courses
- Continuity maintained among the changing instructors of the same course

Concluding Remarks

A systematic assessment process addressing ABET outcomes was carried out with a view to develop the curriculum within a continuous program improvement plan. The new curriculum that started in Fall 2003 includes a thermal-fluid systems design course, a seminar component in capstone design course, a statistics and probability elective, and general education electives better reflecting the cultural and societal outcomes of ABET EAC 2000. We believe that our new B.S.M.E. curriculum, thus developed, better prepares engineering graduates to readily enter the work force in the 21st century. We will monitor the impact of the changes in the curriculum using the assessment tools developed and maintain continuous quality improvement in all our academic programs.

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Biographic Information

Ramana M. Pidaparti received his Ph.D. degree in Aeronautics and Astronautics from Purdue University, West Lafayette in 1989. Since August 1989 he has been with the Department of Mechanical Engineering at the Indiana University-Purdue University Indianapolis (IUPUI) where he is currently Professor of Mechanical Engineering and serves as the Director of Academic Programs. Dr. Pidaparti has published over 130 technical papers in refereed journals and conference proceedings in the areas of composites, fracture mechanics, biomechanics and finite element methods. His current research interests are in engineering design, assessment, advanced composites, biomedical engineering, adaptive devices design, and nanotechnology. He is a member of Tau Beta Pi, Sigma Gamma Tau, and Who's Who societies. He is a member of professional societies including AIAA (Associate Fellow), ASME (Fellow), and ASEE.

Hasan U. Akay received his Ph.D. degree from the University of Texas at Austin in 1974 with a specialization in computational mechanics and the finite element method. Since August 1981 he has been with the Department of Mechanical Engineering at Indiana University-Purdue University Indianapolis (IUPUI), where he is currently Chancellor's Professor and Chair of the Department of Mechanical Engineering. His research area is in development of high-performance parallel computational algorithms for solution of large-scale problems in fluid and solid dynamics. Dr. Akay has published numerous technical papers, book chapters and reports (over 150), and presented invited lectures in various national and international conferences. He is a reviewer of a number of leading journals on numerical methods, fluid dynamics and solid mechanics. He is a member of ASME (Fellow), AIAA, and ASEE.