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# Experiences in the Integration of Design Across the Mechanical Engineering Curriculum

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## ABSTRACT

The Faculty of the School of Mechanical Engineering at Purdue University have effected a major change in the Purdue Mechanical Engineering program by integrating design throughout the curriculum. In doing so, a significant level of faculty interaction has been achieved as well. The goals of the curriculum revision are: (1) to improve student skills in how to solve open-ended design problems, (2) to reduce the core of the curriculum to allow flexibility in course selection, and allow time for solving design problems, (3) to improve student skills in team work and communications, and (4) to improve student skills in using computers as tools for solving engineering problems.

Reduction of the core allowed the addition of a sophomore cornerstone design course. This cornerstone course teaches students how to solve open-ended problems, bridging the gap between solution strategies that are effective for the science and mathematics courses, and those needed to solve open-ended engineering problems. The design fundamentals taught in the cornerstone course are applied in the core courses, such as heat transfer, thermodynamics, instrumentation, and machine design. The senior design experience comes primarily from a design elective and the capstone design course.

This paper presents an overview of the curriculum revision process, and the changes which resulted from it. It also discusses the issues associated with infusing design projects into core courses which have traditionally focused on teaching engineering science fundamentals. Plans for the future evolution of the curriculum are also discussed.


## BACKGROUND

In 1989, the faculty of the Purdue University School of Mechanical Engineering began an extensive study of its academic program, with particular focus on the integration of design throughout the program. The self-study process revealed that, although the School's graduating seniors were very strong in fundamentals pertaining to the engineering sciences (approximately 98% of the students who take the Engineer-In-Training exam pass it), they had little knowledge of design theories, and they had little experience applying them. They also had little understanding of the product realization process, that is, the context in which design problems are often encountered.

Many of the faculty also observed that students tended to view problems as having unique solutions and solution paths, and that students tended to solve problems by matching examples they have previously seen, rather than by applying first principles. Students were also perceived to lack an experience base upon which to build in later courses because they had little exposure to mechanical or thermal systems before entering the program.

Based on the results of the self-study, the faculty concluded that a new philosophy needed to be instilled in the students. Students must be taught in an environment that forces them to become logical problem-solvers, not just imitators and pattern-matchers. They must be made aware of the central role of the designer in the product realization process and the notion of the designer as an integrator of solutions to a complicated array of conflicting goals and constraints. Students must recognize that, to be effective, the designer must not only meet the functional requirements of the product, but also accommodate all the constraints imposed by the marketing, legal, economic, and manufacturing business groups.

It was clear that change this significant could not be achieved in a single course. An open-ended problem-solving mind-set must come from a common theme that permeates the curriculum. Consequently, the faculty set out to infuse this design philosophy throughout the curriculum, through instruction in the design process as well as experience solving realistic open-ended problems. For a curriculum already intense in workload, this would require broad-scale revisions in all courses.

## THE REVISION PROCESS

The School of Mechanical Engineering at Purdue is composed of approximately 55 faculty members, grouped into six areas according to teaching responsibilities. These are design, fluid mechanics, heat transfer, solid mechanics, system measurements and controls, and thermodynamics. Since the integration of curricular content throughout the school is one of the charges of the Curriculum Committee (composed of representatives from each of these areas), the Committee was charged with the task of spearheading the curriculum change.

The key challenge for the Committee was to make room in the existing curriculum for the new approach, and for more project work. To do this, material had to be removed from the core courses (those required of all undergraduate mechanical engineering students). This required the committee members to prioritize material outside of their areas of representation, which encouraged everyone on the committee to study the content and approach in all of the required courses. This was a healthy, though at times tedious, exercise.

Though the Curriculum Committee spearheaded the revision process, all faculty members were involved. Weekly academic area meetings were held to generate input to the Committee, and to respond to proposals coming from it. In addition, the entire Mechanical Engineering faculty met several times in informal settings during which members were encouraged to freely express their views.

As a result, the faculty became more aware of what their colleagues were teaching and how it affected their own courses. In addition, a heightened sense of the need for integrating the curriculum grew, along with the will to bring it about. A sense of loyalty to the overall mission of the school prevailed over any parochial interest that some faculty members may have held for the subject matter in their own academic area.

## THE REVISED CURRICULUM

Tables 1 and 2 show the old and new curricula, respectively. The most significant change is the reduction of the core material by a total of 12 credits while maintaining integrated course sequences in the three major subject areas of: (1) Mechanics, Materials, and Mechanical Design, (2) Thermal and Fluid Sciences, and (3) Systems, Measurement, and Control. A follow-on course is available in each of these three areas, and students are required to complete two of the three follow-on courses as restricted electives. Other significant changes include: the introduction of communications material in the seminar course, ME 290, moving the strength of materials course, CE 273, to the 5th semester (closer to the courses in which that material is used), and the addition of a design elective in the 8th semester. The design elective must be chosen from a list of courses which have 50% or more design content.

### Design Integration

Less obvious from the course listings in the tables is the more significant change in the material presented in the courses, and the integration of the courses. Reduction of the core allowed the addition of a sophomore cornerstone design course, ME 263, to complement the senior capstone course, ME 463, and the senior design elective. This cornerstone course teaches students how to solve open-ended problems and bridges the gap between solution strategies frequently used in science and mathematics courses, and those needed to solve open-ended engineering problems. The goal of the course is to teach fundamental principles for solving design problems, with special emphasis on communications and integrated use of computer tools in the design process. Exposing students to design theory in the context of their semester-long project experience is the key to the success of the sophomore course. Typical projects include: a supplemental car heater to comfort drivers until the engine heater is warm, a quick cooler for warm beverages, a product to demonstrate physics principles for college instructors, and a high-pressure water toy for 12-year-old children. Further details of the course have been presented in Starkey, et. al. (1994).

The foundation of design fundamentals laid in the cornerstone course, ME 263, are built upon in the core courses. Projects are given which require a blending of design process skills emphasized in the sophomore course with basic understanding of the engineering science fundamentals taught in these core courses. The design projects also add relevance to the engineering science content in the core courses.

In the heat and mass transfer course, ME 315, for example, design has been integrated through two major themes (Schoenhals, et. al., 1994): the involvement of an *industrial sponsor* to provide a topic for a design-type project and to interact with the student engineers, and extensive *laboratory and teaming* experiences. The laboratory experience has been expanded in three ways: (1) experiments which require the students, working in two-, or at most three-person teams, to define the objectives, (2) experiments which allow for use of microcomputer skills acquired in earlier instructional laboratory courses (King, et. al., 1994), and, perhaps most important, (3) experiments, many of several weeks duration, which are an integral component of the industrial sponsor's project-type assignment.

Topics for the design assignment during the past semesters have included: a cooling system for a dynamic braking power sink in an electric vehicle, a cryogenically cooled condenser for the recovery of methylene chloride vapor from an industrial waste gas stream, a thermal process for curing an organic film on a torque-converter plate, and the development of a thermal model and related convection coefficients to estimate time-to-defrost an automotive windshield. The design assignments usually were six to seven weeks long and involved at least three laboratory experiments in order to generate design information. For the automobile defroster project, for example, a convection correlation for a windshield was determined experimentally.

The senior design experience comes primarily from the design elective and the capstone design course, ME 463. The design elective, selected from a group of courses such as The Product Realization Process, Design for Manufacturability, Thermal Systems Design, and Engineering Design Using Modern Materials, allows students to broaden their background in design. Students can customize their curriculum by selecting from this list of courses. The open-ended problem solving philosophy introduced in the sophomore course, and reinforced in the required core courses, is embraced in these electives as well.

Because of the integrated design experiences through out the core curriculum, students taking the capstone design course, Engineering Design (ME 463), more fully appreciate the role of the designer as an integrator. Therefore, the projects in the capstone course cover a broader range of technology, involve greater industrial participation, and deal with more multidisciplinary issues (Visser and Midha, 1993). For example, a recent project, involving design of an automated blood analyzer, was developed in cooperation with a major medical instrument manufacturer. Project teams were composed of students from Mechanical Engineering and the Industrial Design Division of the Visual and Performing Arts Department at Purdue. This combination allowed students to address aesthetic and human factors requirements as well as technical issues related to mechanisms, heat transfer, and measurement and control.

These interdisciplinary projects better apprise students of potential benefits as well as operational difficulties of concurrent design methods in product development. They not only provide a fertile ground for innovation and creativity in design, but expose the students to an accelerated product development schedule as well.

### Communications and Computers

Paralleling the integrated design experience, the curriculum also provides an integrated experience in communications and computing. Sophomores are taught communication skills in a seminar course, ME 290, and in the cornerstone course, ME 263. Oral and written reports are critiqued in these courses, so that skills are honed and expectations are set for the core courses which follow. Technical reports are part of the design experience in the core courses and in the capstone design course, ME 463. The faculty have taken on the responsibility of integrating the communications emphasis into the design projects, and a full-time communications coordinator has been hired to develop fundamental material on communications to present to the students.

Computer skills are essential for the engineers of the 21st century, but not at the expense of fundamentals. The challenge has been to develop the skills needed to translate engineering problems into useful computer models. While sophisticated computer software is available to the students for advanced problem-solving, the instructional focus in the sophomore and junior courses is on tools that are simple to use, yet powerful and affordable. This approach allows them to focus on the integration of the computer tools into the engineering problem solving process, rather than striving to gain mastery of specific computer programs.

## FUTURE DEVELOPMENTS

Fully implementing these changes in the curriculum has taken several years. Students enter the new curriculum at the sophomore year in the cornerstone course. Since the first offering of the sophomore course was in Fall 1992, the first students to graduate from the new program will do so in Spring 1995. Consequently, a remaining task is to complete the development of revisions to the senior level courses, particularly the design electives.

A second issue for future development is the reduction of the workload in the new courses. Open-ended problems which require the students to work in groups, to create and evaluate alternative solutions, and to make difficult decisions, take more time than the more traditional single-solution problems they replace. The tendency is to put open-ended problems everywhere, especially when developing new courses and trying out new ideas. The challenge now is to coordinate the projects among the courses so that there are enough open-ended problems to teach the students how to solve them, without over-burdening them with work.

Finally, the curriculum committee is in the process of developing an appropriate instrument to survey graduates to determine the effectiveness of the program in preparing students for an engineering career and to seek input for continued curriculum improvement.

## SUMMARY

The faculty of the School of Mechanical Engineering at Purdue has developed an integrated design curriculum for the 21st century. Keys to innovation have been faculty acceptance of the need for change in mechanical engineering education, willingness to participate in new course development, and willingness to teach across traditional subject boundaries. The result is an adaptable curriculum producing graduates with a sound knowledge of engineering fundamentals and the ability to apply them to open-ended design problems.

## REFERENCES

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Table 1 The Old Curriculum (1990)

FRESHMAN YEAR

32 credit hours as prescribed by Freshman Engineering

SOPHOMORE YEAR

| Third Semester | Fourth Semester |
|---|---|
| (3) General Education Elective | (3) General Education Elective |
| (4) MA 261 (Multi-variate Calculus) | (4) MA 262 (Linear Alg. & Diff. Eq.) |
| (3) PHYS 241 (Electricity & Optics) | (3) CE 273 (Mech. of Materials) |
| (3) ME 200 (Thermodynamics I) | (3) ME 274 (Basic Mechanics II) |
| (3) ME 270 (Basic Mechanics I) | (3) EE 201 (Linear Circuit Anal.) |
| (0) ME 290 (Mech. Engr. Seminar) | (1) EE 207 (Elect. Meas. Tech.) |
| 16 | 17 |

JUNIOR YEAR

| Fifth Semester | Sixth Semester |
|---|---|
| (3) General Education Elective | (3) General Education Elective |
| (4) ME 310 (Fluid Mechanics) | (3) ME 302 (Thermodynamics II) |
| (4) ME 360 (Mechanism Design) | (4) ME 315 (Heat & Mass Transfer) |
| (3) ME 375 (Model & Anal. Phys. Sys.) | (3) ME 385 (Instr. & Model. Phys. Sys.) |
| (3) MSE 230 (Struc. & Prop. Materials) | (3) Electrical Engineering *OR* Mathematics Elective |
| 17 | 16 |

SENIOR YEAR

| Seventh Semester | Eighth Semester |
|---|---|
| (3) General Education Elective | (3) General Education Elective |
| (4) ME 460 (Design for Strength & Reliability) | (6) Technical Electives |
| (3) ME 475 (Automatic Control Systems) | (3) Free Electives |
| (6) Technical Electives | (3) ME 463 (Engineering Design) |
| 16 | 15 |

Minimum total credit hours required - 129.

Notes:
1. General Education Electives include selected courses in Humanities and Social Sciences.
2. Technical Electives include non-required ME courses at the senior or graduate level (400 and 500 level courses) as well as courses from other Schools of Engineering.

Table 2 The New Curriculum (1993)

FRESHMAN YEAR

32 credit hours as prescribed by Freshman Engineering

SOPHOMORE YEAR

| Third Semester | Fourth Semester |
|---|---|
| (3) General Education Elective | (3) General Education Elective |
| (4) MA 261 (Multi-variate Calculus) | (4) MA 262 (Linear Alg. & Diff. Eq.) |
| (3) PHYS 241 (Electricity & Optics) | (3) ME 263 (Intro. Mech. Engr. Design) |
| (3) ME 200 (Thermodynamics I) | (3) ME 274 (Basic Mechanics II) |
| (3) ME 270 (Basic Mechanics I) | (3) EE 201 (Linear Circuit Analysis) |
| (1) ME 290 (Mech. Engr. Seminar) | (1) EE 207 (Elect. Meas. Tech.) |
| 17 | 17 |

JUNIOR YEAR

| Fifth Semester | Sixth Semester |
|---|---|
| (3) General Education Elective | (3) General Education Elective |
| (4) ME 310 (Fluid Mechanics) | (4) ME 352 (Machine Design I) |
| (3) ME 375 (Syst. Modeling & Analysis) | (3) ME 385 (Systems & Measurements) |
| (3) MSE 230 (Struc. & Prop. Materials) | (3) *Restricted* or Technical Elective |
| (3) CE 273 (Mech. of Materials) | (3) Free Elective |
| 16 | 16 |

SENIOR YEAR

| Seventh Semester | Eighth Semester |
|---|---|
| (3) General Education Elective | (3) General Education Elective |
| (4) ME 315 (Heat & Mass Transfer) | (3) ME 463 (Engineering Design) |
| (3) *Restricted* Elective | (3) Design Elective |
| (3) Technical Elective | (6) Technical Elective |
| (3) *Restricted* or Technical Elective | 15 |
| 16 | |

Minimum total credit hours required - 129.

Notes:

1. General Education Electives include selected courses in Humanities and Social Sciences.
2. Restricted Electives. Students must complete two of the following three courses: ME 302 (Thermodynamics II), ME 452 (Machine Design II), ME 475 (Automatic Control Systems)
3. Design Elective. Courses with a minimum design content of 1.5 credit hours qualify as design electives
4. Technical Electives include non-required ME courses at the senior or graduate level (400 and 500 level courses) as well as courses from other Schools of Engineering.