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Experiences in the Integration of Design Across the Mechanical Engineering Curriculum

Dr. John M. Starkey, Dr. Ashok Midha
Dr. David P. DeWitt, Dr. Robert W. Fox

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.
Less obvious from the course listings in the tables is the elective in the 8th semester. The design elective must be which that material is used), and the addition of a design CE 273, to the 5th semester (closer to the courses in 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 more significant change in the material presented in the chosen from a list of courses which have 50% or more courses, and the integration of the courses. Reduction of introduction of communications material in the seminar allowed the addition of a sophomore cornerstone of the core material by a total of 12 credits while respectively. The most significant change is the reduction 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

King, G.B., R.D. Evans, D.P. DeWitt and P.H. Meckl,
1994, "Curriculum-wide Systems Programming
Environment for Mechanical Engineering Instructional
Laboratories," Session 4C1, ASEE Frontiers in Education
Conference, San Jose, November 1994.


Table 1 The Old Curriculum (1990)

<table>
<thead>
<tr>
<th>FRESHMAN YEAR</th>
<th>32 credit hours as prescribed by Freshman Engineering</th>
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<tr>
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<td>(3) General Education Elective</td>
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<td>(4) MA 261 (Multi-variate Calculus)</td>
<td>(4) MA 262 (Linear Alg. &amp; Diff. Eq.)</td>
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<td>(3) PHYS 241 (Electricity &amp; Optics)</td>
<td>(3) CE 273 (Mech. of Materials)</td>
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<td>(3) ME 200 (Thermodynamics I)</td>
<td>(3) ME 274 (Basic Mechanics II)</td>
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<td>(3) ME 270 (Basic Mechanics I)</td>
<td>(3) EE 201 (Linear Circuit Anal.)</td>
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<tr>
<td>(6) Technical Electives</td>
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</table>

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)

<table>
<thead>
<tr>
<th>FRESHMAN YEAR</th>
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**FRESHMAN YEAR**

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**SOPHOMORE YEAR**

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**JUNIOR YEAR**

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**SENIOR YEAR**

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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.