The Design Spine: Revision of the Engineering Curriculum to Include a Design Experience each Semester

Keith Sheppard and Bernard Gallois
Charles V. Schaefer, Jr. School of Engineering
Stevens Institute of Technology
Hoboken, New Jersey, 07030

The Stevens engineering curriculum was recently revised to extend the design experience to every semester and in effect create a *Design Spine*. This metaphor additionally reflects the other major change to provide a much greater level of integration between engineering science and design courses to enhance learning. Open-ended projects together with experiments in the design courses are chosen to provide context for and reinforce the engineering science taught concurrently. The *Design Spine* will also provide the vehicle to develop key competencies in problem solving, effective communication, project management, ethics, economics of engineering, teaming and industrial ecology in an evolutionary manner throughout the sequence.

1. Introduction

It has been estimated that approximately 70% of the life-cycle costs of product realization, i.e. the conception, development and bringing to market of a product, are determined during the design phase[1]. There has been a growing recognition that engineering curricula in the U.S. have not been providing sufficient and appropriate emphasis on design to meet the needs of competitive business practice in an intensive global marketplace.

The First Phase of Design Enhancement at Stevens

In 1991 Stevens Institute took a significant step towards addressing the improvement of competencies associated with design by the introduction of a *Design Thread* that included three new core design laboratories. These courses were added in the second semesters of freshman, sophomore and junior years respectively to complement the traditional one-year capstone senior design project. The design thread also included an existing Engineering Graphics course in the first semester of the sophomore year. A two-course sequence (increased from one) in engineering management was also considered part of the design thread through its contribution to the economics of design.

Adjunct faculty who were either practicing or recently retired engineers taught the three core design courses. This mode has proved very effective and students appreciate the experience the instructors bring to the class; it helps link the design classes to the "real world". Some classes have successfully utilized senior undergraduates as peer instructors to assist the faculty member.

The *Design Thread* was a relatively early response to what has become a national trend to strengthen design education as evidenced, for example, by the extensive design-related curricula development and implementation activities of the various Engineering Education Coalitions sponsored by the National Science Foundation[2].

The Recent Curriculum Revision

In 1998 the Stevens faculty started implementation of a revised engineering curriculum to build upon the experience with the *Design Thread*, to strengthen the core sequence and to provide better alignment with ABET Criteria 2000. The revision had its origins in an Institute-wide strategic planning activity that, for the Engineering Curriculum, reaffirmed the core values associated with the Stevens tradition of a large, broad-based core while allowing for accreditation in various engineering disciplines.

Curriculum Development Process

The curriculum revision was a result of several years of development that involved definition of educational goals and objectives, competencies based on the goals and the articulation of these into the curriculum. This process involved a number of faculty committees and also sought contributions from outside experts and alumni from industry, academe and government through individual discussions and round tables. Benchmarking of curriculum development activities at other institutions was also undertaken, particularly in the areas of design and integration. Meetings were held with groups of junior and senior undergraduates to seek input. A survey of recent graduates and their employers was conducted by Prof. P. Koen of the Management Department and addressed the perceived competencies of these alumni[3]. The results were consistent with those from other surveys and reports[4] in indicating that graduates met expectations in the technical competencies. However, there was a need for further enhancement of competencies in the "soft" areas such as problem solving, teaming, communication skills and project management; competencies that can be addressed as part of design education.

2. The Design Spine

As a result of the development activities described above, a cornerstone of the revised curriculum is a further strengthened design sequence forming a *Design Spine* running through all eight semesters. Associated with the development of the *Design Spine* is a greater integration of design with the science and engineering science courses, in many cases with courses taken concurrently.

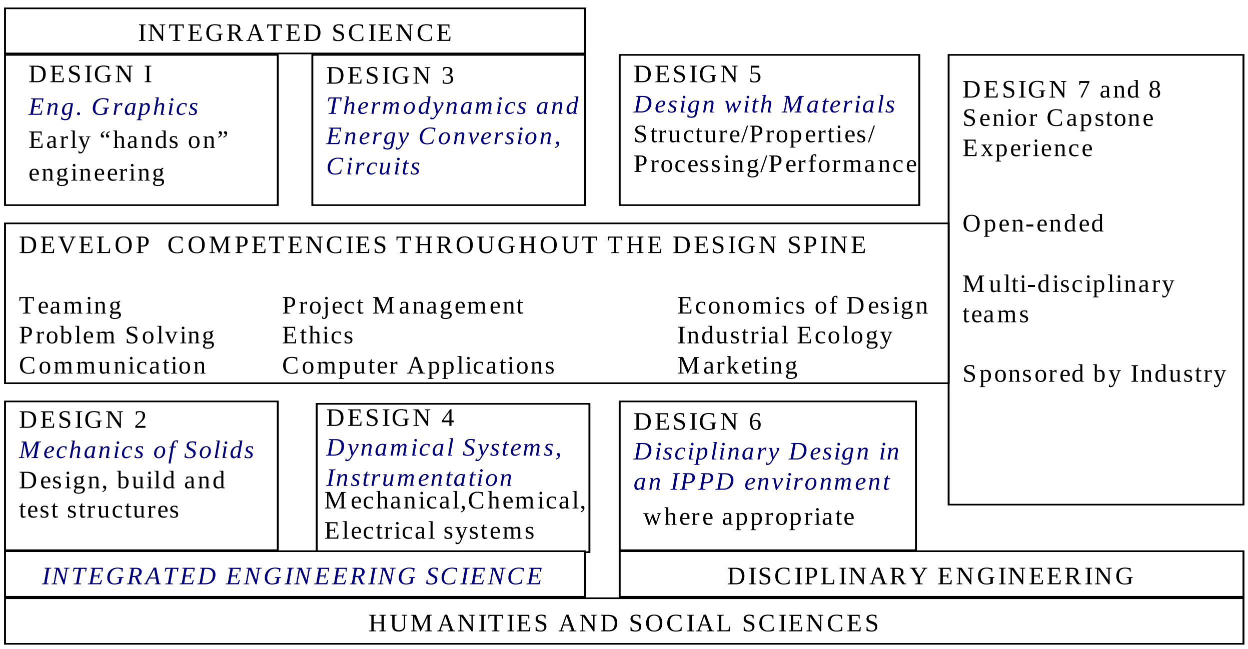
A schematic representation of the *Design Spine* and its relations to other components of the curriculum appears in Figure 1. Within each box representing a design course is shown, in italics, the engineering science course(s) with which the design course is integrated. At the center are shown the key competencies that are developed throughout the design sequence.

The *Spine* consists of five core design courses (Semesters 1 through 5). The first four design courses are structured such that students are exposed in some way during their first two years to design issues associated with each of the main engineering disciplines.

There are three disciplinary design courses (Semesters 6-8) that are integrated with the technical elective courses for the student’s concentration. The disciplinary design courses do, however, contain some required core topics that are required of all students and these topics are covered in a modular approach, for example integrated product and process design.

The threads on communications, use of computers and social, ethical and moral issues are also enhanced in the *Design Spine* compared to the previous curriculum. A new thread on industrial ecology (e.g. life cycle analysis and design for environment) is added to address what will increasingly become an overarching consideration in the engineering profession, namely sustainable growth. This thread commences in Design 2.

Figure 1 DESIGN SPINE OUTLINE



Freshman Design

The sequence starts with a one-credit course, Engineering Design 1, taken by entering Freshmen. This is a key change to the curriculum and reflects the success of other schools[2] in implementing first semester design as well as our previous experience with teaching design to Freshmen in the second semester. Starting the *Design Spine* from "day one" provides a valuable, early hands-on design experience to give both balance and context for what students typically perceive as the rather abstract nature of the courses in the traditional Freshman year. It is intended to immediately engage students and generate enthusiasm for engineering. It also sets the tone for their educational development.

The Design 1 course is taken concurrently with Engineering Graphics, which has been moved from the third to the first semester. This move also coincides with a change in the teaching of this course from a 2-D mode using AutoCad™ to a 3-D solid modeling approach using SolidWorks™. We consider this to be a major enhancement in the teaching of Graphics and eminently suitable to help engage Freshmen engineering students.

The Design and Graphics courses are linked in a number of ways. For example, a plastic Logo plate is designed in the Graphics course and is then manufactured on a CNC machining center in the design laboratory. The plate is also designed to meet specifications for mounting on a microprocessor-controlled hill climb vehicle, which is the second design project in Design 1.

Linkage between Graphics and Design 1 is also apparent in a product disassembly workshop in the design course that involves comparing the parts of a cordless screwdriver to working drawings supplied by the manufacturer[a]. This workshop also involves an introduction to free-hand sketching and to orthographic projections, the latter being also covered in the Graphics course. The first semester experience is described in more detail in another paper[5].

In this manner we establish the theme that is to permeate the Design Spine, namely that there is a measure of integration between the design course in a given semester and the engineering science (or science) courses taught concurrently or in the preceding semester.

A continuous sequence of integrated design experiences through the S*pine* is expected to considerably enhance the prospects for mastery of the competencies that the enhanced design sequence is intended to address and that are embodied in the goals of the curriculum. The integration will also enhance the learning and understanding of science and engineering science concepts in the curriculum.

In keeping with the competencies desired of engineering graduates, the design spine includes an increased emphasis on professional practice topics of communication skills, teaming, project management and economics of design. These topics are developed progressively and reinforced throughout the design spine. For example, concepts of project management such as work breakdown and the Gantt chart are introduced early in Design 1 and used in a case study (building a house) and two design projects. The thread on economics of design is initiated in Design 1 through an assembly costing exercise as part of the product dissection workshop followed by consideration of fabrication (machining) costs for the Logo. The students' experiences with group activity (often not positive) are used as a lead in to the more formal consideration of group dynamics starting in the second semester of Freshman year in Design 2. Effective oral and written communication is taught and tested throughout the *Spine*. The Ethics thread starts with consideration of the space shuttle Challenger disaster in Design 2.

While a degree of linkage is established between Graphics and the Design 1 course in the first semester, it is in the second semester that integration of design with engineering science is significantly addressed for the first time in the curriculum. During the curriculum development process it was decided not to attempt the high level of integration that has been implemented at some schools, such as Drexel University (E4 Program) and Rose-Hulman Institute of Technology (Integrated First Year). It was decided that the benefits demonstrated by integration at the schools mentioned (and others) could be achieved at Stevens through a strong linkage between the engineering science courses and a design course given concurrently or immediately

[a] Black and Decker (U.S) Inc., Towson, Maryland.

after. In this regard it was considered not always necessary for the engineering science to be formally covered before its use in design. For example, simple truss analysis is used in Design 2 before it has been fully developed in the concurrent Mechanics of Solids course in the second semester. It can sometimes help students to recognize the need to learn the theory if they have first applied the analysis in a heuristic fashion to a design problem before formal coverage in lectures.

The Mechanics of Solids in the second semester is a 4-credit course that combines the traditional Statics and Strength of Materials courses from the previous curriculum. This is strongly linked to the 2-credit, 3-hour per week Design 2 course. This combination has students learning the theory of engineering structures while concurrently designing, building and testing structures. This also allows some topics to be introduced through the design course rather than first through lecture. For example, the concept of Factor of Safety is introduced and developed through an experiment in Design 2. Other experiments in Design 2 address Friction, Beam Bending, Effects of Stress Concentration and Buckling of Columns. The introduction and significant use of spreadsheet software[b] for data analysis, including simple statistics, is part of the course. There are two design projects, the first of which is to design, make and test a simple soldered brass truss. The second involves analysis of beam bending to facilitate the design of a shop hoist. These projects link directly to and reinforce concepts covered in Mechanics of Solids.

Design 2 also initiates the Industrial Ecology thread by consideration of the life cycle analysis of a simple wooden product with a mechanical application, such as a ladder. The professional practice threads are continued with introduction of some basic concepts of engineering economy (e.g. time value of money and interest rates linked to the second design project), group dynamics and further development of cost estimation and project management, including use of project management software[c]

Based on the positive experience in the design courses of the previous curriculum, we have continued with the use of engineering professionals as adjunct instructors for the Freshman design courses supported by undergraduate peer instructors. We continue to receive good evaluations from students for this mode of teaching design.

The integration continues in Semester 3 with the 2-credit Design 3 course linked to both a 3-credit Circuits course and a 4-credit Thermodynamics and Energy Conversion course. Again the design course reinforces material in the engineering science courses through the use of experiments and design projects. Designs use bread-board level circuit design that would include logic and signal conditioning. A typical design project would involve energy conversion, one adapted from the previous design thread is a solar-tracking water heater.

The 2-credit Design 4 course is linked to a new core course at Stevens on Dynamical Systems and to the Electronics and Instrumentation course given concurrently. The Dynamical Systems

[b] Microsoft Excel™
[c] Microsoft Project™

course recognizes that there is a commonality among the engineering disciplines when taking a systems approach. This commonality is manifested in the time-dependent nature of the physical models used to analyze diverse systems from pumping systems in industrial processes to structures subject to vibrational loading to control systems in aerospace applications. Projects include design of a mechanical vibration isolator, design of an electrical compensator and design of a muffler. Experiments include frequency response of a speaker, stabilization of an amplifier, response of a pump system, response of a vibrating cantilever. Experiments and design projects promote significant use of computer-based instrumentation for data acquisition, analysis and control with vertical integration of software[d] with other design and laboratory courses.

The fifth design course, Design 5 (2 credits), is an evolution of an existing Materials Laboratory and is coupled to a 3-credit Materials Processing course. The latter replaces a traditional sophomore level "Introduction to Materials" course, with much of the materials science now covered in the revised chemistry and physics sequence. The laboratory course maintains many of the previous experiments, which already had a strong processing orientation. Two significant design components are now included, one linked to processing of the major classes of materials, the other stresses how to design with materials in several engineering disciplines. The laboratory also continues to emphasize the development of experimental skills and methods.

The sixth design course is intended to allow each discipline to address design topics specific to the discipline, but in the context of how design in the discipline fits into an integrated product and process development (IPPD) paradigm as and if appropriate.

Components of professional practice/economics of design are developed throughout the Design 1 through 6 sequence building in an evolutionary manner on the foundation that has been described for the Freshman year. They account for a significant content of each of the design courses. It is through exposure to this material and associated experiences that many of the key competencies shown in the center box of Figure 1 are advanced. They are further developed in a two-course sequence (not shown in Figure 1), a 4-credit lecture/laboratory course in Semester 6 and a 2-credit lecture/laboratory course in Semester 7. These courses allow for material that is best developed in that format rather than in the more distributed form of the earlier design courses, such as more advanced concepts of engineering economy and decision making. As such the curriculum preserves and enhances the strong emphasis on professional practice/economics of design from the previous curriculum while moving material earlier into the *Design Spine* to provide better context and a more evolutionary development of the concepts.

The ultimate goal for the senior design experience (Design 7 and 8) is to allow students to capitalize on the competencies they have developed in teamwork and other skills and knowledge through the S*pine* and their elective sequence. In this way they are equipped to participate effectively in cross-disciplinary systems-scale projects sponsored by industry.

[d] for example LabView™ and MatLab™

It is anticipated that we will have increasing numbers of interdisciplinary projects as the Sponsored Senior Design Program, a component of our Pre-professional Programs evolves. Significant progress has been made to increase the role of industrial sponsorship of senior design at Stevens, but the projects have to date remained mostly disciplinary in nature. We are working to move to larger interdisciplinary projects that better represent the environment that our students will find themselves in as they enter the engineering profession.

3. Assessment

The Stevens Assessment Plan is intended to address the requirements of ABET Criteria 2000 for assessment of educational outcomes. It establishes curricula goals, a set of objectives associated with each goal and Performance Criteria for each Objective. These are mapped to course performance criteria. Implementation of the Plan has made good progress with the course performance criteria emerging as part of the implementation process for the revised curriculum. Assessment tools include a significant web-based component (see http://attila.stevens-tech.edu:1350/). In this way course development has and is taking place with the Assessment Plan as a companion and contributor to the process. Thus alignment to ABET Criteria 2000 is built into the implementation of the revised curriculum. It should also be noted that even in developing the structure of the curriculum prior to implementation, full heed was taken of the needs of ABET 2000. The Design Spine especially, was structured based on a set of desired competencies and the appropriate evolution of these through the sequence was a major guiding factor.

Bibliography

1. "Improving Engineering Design: Designing for Competitive Advantage", National Research Council, Washington, D.C., 1991.
2. Links to NSF Engineering Education Coalition activities available at http://www.needs.org/coalitions/
3. P. Koen, "Using an Industry Survey to Obtain Faculty Support for ABET 2000", 1998, ASEE Annual Conference Proceedings, Session 2642.
4. For example the following reference and reports cited therein: "Engineering Education: Designing an Adaptive System", Board on Engineering Education, National Research Council, National Academy Press, Washington, D.C., 1995.
5. R. Cole, B. Gallois and K. Sheppard, "Redesigning the First-Year Engineering Curriculum", 1999, ASEE Annual Conference Proceedings, Session 3325.

KEITH SHEPPARD is a Professor of Materials Science and Engineering and Associate Dean of Engineering. He earned the B.Sc. from the University of Leeds, England and Ph.D. from the University of Birmingham, England, both in metallurgy. As Associate Dean, Sheppard coordinates the development and implementation of the courses that comprise the core design sequence at Stevens.

BERNARD GALLOIS is Dean of Engineering and Professor of Materials Science and Engineering. He received the Diplôme d' Ingénieur Civil des Mines at the École Nationale Supérieure des Mines de Nancy, France. He obtained the M.S. and Ph.D. degrees in metallurgy and materials science from Carnegie Mellon University. As Dean he has lead the recent revision of the Engineering Curriculum at Stevens and the development of associated infrastructure.