

The International Journal of Engineering Education

SPECIAL DOUBLE ISSUE

Design Education for the 21st Century

Guest Editors: Clive Dym and Sheri Sheppard

Contents

- M. S. Wald** 321 Editorial
- C. L. Dym and S. D. Sheppard** 322–323 Introduction and Overview
- J. W. Wesner** 324–326 Key Learnings and Commitments from Mudd Design Workshop II

The final, wrap-up Session of Mudd Design Workshop II was designed to achieve two goals: (1) identify the key themes brought out during the entire workshop; (2) elicit commitments from the participants, to apply workshops ideas of their choice in their own classrooms during the next two years (in anticipation of reporting results to the next Mudd Design Workshop). Each session leader had been asked to capture in a few sentences the most important themes from their session, and any issues that had arisen; they presented them to the group of participants at the wrap-up session. These themes and issues were written on Post-It[®] Notes, and the participants used Affinity Diagramming to identify from the session input the overall key themes identified during the workshop. Finally, the participants committed to try ideas from the key themes or the session themes and issues in their own classrooms. People were enthusiastic about the workshop learnings, and were very willing to do this. The commitments were written down, so that people can be reminded of what they said they would do.

'People' Issues

- R. A. Faste** 327–331 The Human Challenge in Engineering Design

The fundamental need for engineering in the new century is to acknowledge and embrace the human nature of its endeavor. This paper describes a spectrum of humane concerns beginning with straightforward design issues and escalating to philosophical assumptions about the nature of man. It is my contention that engineering must either enthusiastically incorporate a broad view of humane concern, or make room for a profession that will.

- F. J. Fronczak** 332–335 Design Engineers—Fast, Cheap, or Good—Pick Any Two of the Three

This paper presents the argument that Engineering Design is a complex process requiring knowledge, skill, and attitude. While knowledge can be taught, skill and attitude cannot. Instead, skill can be developed and attitude can be cultivated and nurtured. It is argued that the development of design skills, and the cultivation of the attitude needed for successful design require much more effort and a more individual approach than that which is needed to merely pass on knowledge. This is a necessarily time consuming and costly process. Consequently, if our goal is quality, we must be willing to expend considerable time, at necessarily considerable cost, in order to achieve this goal.

- B. Bender** 336–342 Concepts for Purposive and Motivational Teaching and Learning in Engineering Design Courses

New technologies demand new qualifications and new teaching concepts. Sole reliance on intuition and previous experience is insufficient. The Technical University of Berlin uses a systematic approach to learning/teaching which adopts a holistic approach to problem solving embracing the new technologies. This ensures that the way of teaching changes as much as the way of learning.

Teams and Collaboration

- P. L. Hirsch, B. L. Shwom, C. Yarnoff,** 342–348 Engineering Design and Communication: The Case for Interdisciplinary
J. C. Anderson, D. M. Kelso, G. B. Olson
and **J. E. Colgate** Collaboration

This paper describes an innovative, interdisciplinary, project-based freshman course at Northwestern University—Engineering Design and Communication (EDC). The course fully integrates engineering design with freshman communication and is taught collaboratively by faculty from Engineering and from Arts and Sciences. Working on real projects for real clients, students acquire skills in communication, design, and teamwork and also come to see design and communication as complementary parts of the same iterative and creative problem-solving enterprise. We argue that this interdisciplinary approach improves the teaching of both communication and design and provides students with an exceptionally solid foundation for their future engineering courses and careers.

- S. Kuhn** 349–352 Learning from the Architecture Studio: Implications for Project-Based Pedagogy

Architects are educated through a process that revolves around the 'studio course', and an attempt to apply the studio method of teaching to the education of software designers reveals much about education and practice in both professions. Characteristics of the architecture studio include: project-based work on complex and open-ended problems, very rapid iteration of design solutions, frequent formal and informal critique, consideration of a heterogeneous range of issues, the use of precedent and thinking about the whole, the creative use of constraints, and the central importance of design media. Experience from a studio course in software design provokes creative reflection on engineering design education, and on how it might be improved.

D. G. Taylor, S. P. Magleby, R. H. Todd 353–358 Training Faculty to Coach Capstone Design Teams
and **A. R. Parkinson**

During senior capstone experiences, student teams are often given a faculty advisor to teach and assist them. Our experience has shown that using the traditional student/faculty teaching model is not an efficient or effective approach to the student learning of design and team processes. The objective of the paper is to show that successful learning experiences for capstone design teams require faculty to shift their role from a traditional lecture or consulting role to a coaching role. Research into key indicators of engineering design team success related to coaching focused on team observations, individual and team interviews, and individual team member and coach surveys. Results shows that a successful coaching role encompasses three main responsibilities: mentor, mediator and manager. Specific expectations and activities that a coach should fulfill to aid in the success of capstone teams can be established.

N. J. Delson 359–366 Increasing Team Motivation in Engineering Design Courses

Team motivation in capstone engineering courses can significantly affect the quality of project outcome. Teams with high motivation often exceed expectations, while less motivated teams at times fail to reach the potential of even a subset of their members. Successful teams typically exhibit a high level of independence in decision making and engineering implementation. However, many components of traditional classroom settings and student projects can hinder team motivation. Moreover, some experiences with student teams have been counterintuitive; groups with slow or rocky starts may end up with higher levels of achievement, while heightened instructor interest in a project topic may result in a detrimental effect on student work. Team motivation is specifically addressed by research in the area of organizational behavior and group processes. This article will apply some lessons derived from group process research to the objective of increasing motivation in student design projects. Relevant input is provided in the areas of project selection, role of instructor, sources of feedback, independence of groups and stages of team development. In addition, familiarity with group processes can increase the quality of the instructor's experience during the inevitable turmoil associated with ambitious student projects. Examples of successful and less successful mechanical engineering capstone design projects are presented to illustrate how team development affects the engineering outcome.

Products and Projects

D. Harris 367–369 A Case for Project-Based Design Education

Many engineering curricula are partitioned into laboratory classes and theory classes. Theoretical lecture courses can cover the largest volume of material, but are often criticized for not engaging students, and, as a result, instilling little retention of the material. This paper contends that we teach engineering more effectively by integrating the theory with hands-on design projects. This contention, of course, is not new, yet the partition remains in all too many subjects. This paper describes an ongoing experiment of adding design laboratories to Harvey Mudd's Computer Engineering class, historically a purely theoretical subject. It then address some of the benefits and challenges that may carry over to integrating theory with laboratories in other courses.

P. E. Doepker 370–374 Integrating the Product Realization Process into the Design Curriculum

Industry-sponsored team projects have been implemented in design-related project courses. Although many of these courses are capstone-type courses, some may be laboratory project courses linked with more traditional design courses. This paper outlines the implementation of the Product Realization Process (PRP) in team design projects. The major elements addressed are formation of teams, defining specifications, developing conceptual and final designs, written and oral communication, grading of projects and assessment.

R. E. Apfel and N. Jeremijenko 375–380 SynThesis: Integrating Real World Product Design and Business Development with the Challenges of Innovative Instruction

SynThesis: Product Design and Business Development for Entrepreneurial Teams is a new curricular offering at Yale University that brings together engineering, computer science, and management students into entrepreneurial teams to create new products and business plans. The evolution of the design of this full-year course is described herein, including the objective of orienting the course deliverables to product-based learning; the use of external validation and peer evaluation; close relationships with industry; privileging a team-based reward systems; reinforcing collaborative learning and problem solving; delivering just-in-time course materials; and aligning projects and self-assembling teams with the concerns of the students. The paper also elaborates on methods of course assessment and student and team self-assessment.

C. D. Pionke, J. R. Parsons, J. E. Seat, 381–385 Balancing Capability, Enthusiasm and Methodology in a First-Year Design Program
F. E. Weber and D. C. Yoder

The Engage program is a successful new approach to first-year engineering studies that is being implemented at the University of Tennessee. This program develops the desired attributes of engineering graduates that are requested by industrial employers by introducing realistic design problems and approaches in parallel with introductory technical concepts. The resulting program integrates instruction in computer tools, graphics, statics and particle dynamics in two team-taught six-hour courses, each with parallel team design projects.

T. M. Regan, J. W. Dally, P. F. Cunniff, 386–390 Curriculum-Integrated Engineering Design and Product Realization
G. Zhang and L. Schmidt

In 1991 we began a major change in educating engineering students at the University of Maryland. We reversed the classical sequence of teaching mathematics, science, engineering science, and then finally design. Our teaching methods were changed dramatically from large lecture classes to small classes taught by an instructor who coaches more than lectures. The framework is extremely robust, and it has become an exportable platform for course development across the country. We believed that through re-engineering our educational programs, including the vertical integration of the product realization process throughout the curriculum, we could add sufficient value to our graduates' educational experience that will enable them to compete in the increasingly international engineering marketplace. Among these curriculum changes within the Clark School, we selected four pivotal courses to highlight in this presentation: ENES 100 'Introduction to Engineering Design', ENME 371 'Product Engineering and Manufacturing', ENES 120 'Statics' and ENES 220 'Strength of Materials'.

C. L. Caenepeel and C. Wyrick 391–395 Strategies for Successful Interdisciplinary Projects: A California State Polytechnic University, Pomona, Perspective

An innovative interdisciplinary capstone activity is described that integrates theoretical and experiential education in preparing undergraduate students for engineering, science, and business careers. The model uses real projects funded by corporations. The success of the program is in part attributable to the effective use of team building training as well as peer-based and team-based performance reviews. Team building introduces participants to a strategy to increase group cohesiveness and productivity. This training involves the completion, interpretation and discussion of the Myers Briggs Type Indicator (MBTI). The effective use of peer-and team-based performance reviews reinforces the techniques presented during team building. The criteria for client, project and team selection are summarized. A MBTI analysis of a set of teams, and the rationale for peer and team-based performance reviews are included.

The Design Internship in Pollution Prevention at The University of Tennessee is an honors capstone design course in which source reduction is incorporated into the design of industrial processes. In this activity pollution prevention through basic flowsheet development and equipment selection is emphasized rather than conventional treatment of the effluent waste streams. This activity was begun in 1990 and has involved 128 students and 32 projects. The number of projects per year has varied from 1 to 8. The output of each of these activities is a design report. An important benefit of these activities is an intensive process design experience for the students that emphasize pollution prevention concepts. The paper summarizes accomplishments and lessons learned.

S. P. Magleby, R. H. Todd, D. L. Pugh and C. D. Sorensen 400-405 Selecting Appropriate Industrial Projects for Capstone Design Programs

Clearly industry projects can provide great benefits in an academic design program, but can also become problematic to manage, and can overshadow the educational goals of the Program. In order to have successful experiences with industry sponsored projects, there must be careful definition, management and monitoring. Projects tend to fall into three categories: 1) new product development projects, 2) manufacturing process equipment, and 3) projects that involve systems integration. There are a number of different sponsor situations that affect project management and outcomes. An outline and discussion on the guidelines to be used in recruiting and selecting of industry-sponsored design projects follows.. Leaning too far to either the academic or the industrial side in selection of projects can prove to be problematic.

P. Little and J. King 406-409 Selection Criteria for Cornerstone and Capstone Design Projects

While many engineering programs have long offered capstone design courses, more are beginning to offer a cornerstone introductory project-based course as well. At Harvey Mudd College, this has been the accepted practice for almost 40 years. This paper presents the considerations used in selecting projects for both the introductory course and the capstone Clinic Program, and notes the key differences and similarities in selecting projects. Both programs use actual clients from outside the college, and both expect the students to learn aspects of professional practice beyond intellectual techniques and skills. In both cases, the key to selecting successful projects is to focus on the ability of the students to perform the project, and the relationship of the project to 'real-world' engineering.

D. M. Cannon and L. J. Leifer 410-415 Product-Based Learning in an Overseas Study Program: The ME110K Course

Experience in a foreign country has long been considered a vital part of a well-rounded education. Engineering students, though, seem to have been considered an exception; many students and educators see such experience as being unnecessary, or an unaffordable luxury, given the large number of subjects that are required in the undergraduate curriculum. Stanford University has made a commitment to making overseas study available to as many students as possible, including those who don't traditionally participate. A prime example of that effort is found in the Spring quarter Stanford Center for Technology and Innovation, a program held at its Kyoto, Japan overseas campus, targeted specifically at students in engineering and science programs. Required courses are made available through videotape, live discussion, and such, with the support of on- and off-site professors and teachers' assistants. Expanding on this, we have begun an overseas design project course, aimed ultimately at fulfilling the ABET capstone design course requirements for upper-level engineering students. In this paper we report briefly on the first iteration of the course, taught in the Spring quarter of 1998 in collaboration with Prof. Itsuo Ohnaka of Osaka University. Students in the course teamed up to work on design projects sponsored by four Japanese companies. Because of this unique setting, it was possible to educate the students about the influence of culture on design, creativity, perception of needs; about conventional and unusual approaches to teamwork; and about often culture-dependant assumptions about what criteria an acceptable solution must possess. Studying design in such a foreign context, we have found, can be an extraordinary, eye-opening experience, enabling students to better see the context of their future work, especially as more and more will take place in a global arena. The course was taught again in the Spring of 2000, and included students from Osaka University in the project teams. As of this writing, preparations are underway to carry it out again in the Spring of 2001 in Kyoto and Berlin overseas campuses, with further enhancements.

B. I. Hyman 416-420 From Capstone to Cornerstone: A New Paradigm for Design Education

This paper proposes a new role for the traditional capstone design course that culminates many undergraduate engineering curricula. We envision the outcome of the capstone experience serving as the cornerstone for an integrated sequence of design projects throughout the curriculum. In this paper we describe the benefits of this approach to students, faculty, the university, and industrial clients. While this paper describes how this transformation could be accomplished in the Mechanical Engineering Department at the University of Washington, we believe that it has similar potential in other departments and universities.

Science and systems for the design toolbox

T. R. Kurfess 421-425 Challenges and Directions for Integrating Mechatronics into Early Design

This paper presents the initial results of integrating mechatronics into a large second-year design course. Issues related to course objectives, implementation, costs and initial results for the course are presented as well. The initial results generated from a group of 20 students provides some insight into the ultimate goal of implementing the enhanced curriculum for approximately 300 students per year.

R. Fruchter 426-430 Dimensions of Teamwork Education

This paper discusses key issues related to the pedagogical approach, the learning and team work culture, the choice and scope of projects, collaboration and information technologies employed, and new metrics and assessment methods that need to be considered in the development and deployment of team-oriented, project-based cross-disciplinary teamwork education programs.

W. H. Wood 431-435 Unifying Design Education through Decision Theory

Teaching design effectively is challenging. The state of design as a discipline leaves us with disjoint methods and methodologies that model various aspects of the design process but do not work together. This paper proposes decision theory as a means of potentially unifying design as a process of decision-making under uncertainty. A design exercise is described which strives to model the richness of a real design problem compressed in time and scale to a manageable size. Experience with this exercise reveals decision-based design as a promising pedagogical approach for design education. However, before we can use decision theory to unify design, we must first embrace uncertainty in problem solving throughout the engineering curriculum.

B. Linder and W. C. Flowers 436-439 Integrating Engineering Science and Design: A Definition and Discussion

An important goal of an undergraduate engineering curriculum is to facilitate students' development of an integrated understanding of engineering. Although attempts have been made to integrate engineering science and design curricula, many students are not developing knowledge and skills that synthesize the subjects covered by these two curricula. A few observations of student performance are provided that suggest this lack of integration. A definition of integration is proposed and used to discuss possible reasons why engineering science and design curricula are not well integrated. The definition is based on the observable outcomes and behavior students produce while engaged in learning activities. Mismatched learning objectives, excessive focus on outcomes and inconsistent learning contexts are identified as causes. Finally, suggestions are given for improving engineering curricula based on this discussion.

S. D. Sheppard 440-445 The Compatibility (or Incompatibility) of How we Teach Engineering Design and Analysis

This paper begins with an overview of some of the issues and challenges of teaching engineering analysis and design. It continues with a summary of a design exercise that was run as part of the Mudd Design Workshop II; this exercise was intended to be the foundation and springboard for a discussion on analysis and design education by workshop participants. The design exercise demonstrated that there is both compatibility and incompatibility in how we combine/juxtapose the teaching of engineering design and analysis. Our educational system has many elements that support our students becoming competent in both design and analysis. What is generally missing are opportunities for their use in an integrated manner. Some ideas are presented about how this integration might be fostered.

T. Arciszewski and S. Lakmazaheri 446-454 Structural Design Education for the 21st Century

The paper discusses the future of the structural design education. It provides a brief description of the present situation and of factors shaping it, including information technology. Next, a vision of a future structural engineer is presented and his/her major desired abilities are identified. Structural design education is divided into teaching conceptual and detailed design. In the first area, design and inventive engineering are briefly discussed, including the initial teaching experience. In the area of teaching detailed design, three network-oriented computer tools, Dr. Structure, OleSteel, and Engineering Mechanics Digital Library, are overviewed. The first one was developed at George Mason University, while the remaining two at the Catholic University of America. Also, the initial experience with using all three tools is discussed.

C. Briggs 455-459 On the Role of CAx in Design Education

The tension that has been created by the industry pull for CAD and CAE skills in engineering graduates is explored by surveying the current state of industry practice. Proposing that industry needs are a predictor of changes in engineering education, examples from computer-aided drafting, computer-aided design, computer-aided engineering and computer-aided manufacturing are provided. The paper concludes with support for multidisciplinary capstone projects in the educational experience and a brief look at trends that might predict the rate of adoption of CAD in educational programs.

S. J. Lukasik and M. Erlinger 460-467 Educating Designers of Complex Systems: Information Networks as a Testbed

The needs of modern societies, coupled with the ever increasing power of technology, encourage the development of systems of enormous complexity. Examples are contemporary infrastructures such as transportation, energy, and information, often described as 'systems of systems'. Coping with such complexity is a central problem for their architects and operators. Complex systems behave in unanticipated ways and they have failed spectacularly. The factors influencing system failure go beyond the purely technical, to matters of organization, management, operations, training, regulation, and market incentives, all concerns of the engineering profession. Failures often result from subtle combinations of such factors. Public policy has been directed to the vulnerabilities of national infrastructures, especially as they can be disrupted by both inadvertent failure and malicious attack. If engineers are to increase the robustness of the systems they design and operate, they must recognize the phenomenon of emergent properties rooted in the scale and 'depth' of the system. The Internet, while an operational infrastructure, is also capable of supporting experimentation without the knowledge of, or interference with, its users. Harvey Mudd College's CS 125 course, Computer Networking, covers principles and practices of computer networking. The course has a significant project component that relies on the Internet as an experimental facility. Oversight of such educational and research activities is required if network performance is not to be degraded or user privacy violated. Several examples are presented. An appreciation of emergent properties of systems should be a baccalaureate-level goal, not simply for computer science curricula, but for all of systems engineering.

G. B. Olson 468-471 Brains of Steel: Mind Melding with Materials

A systems approach to the computational design of materials as dynamic multilevel structures integrates process/structure/property/performance relationships based on mechanistic understanding. In analogy to the structure of materials, new insights into the structure of the human brain provide a mechanistic basis for the design of engineering education. The development of the highest-level emotional/synthetic functions controlled by the limbic system is best achieved by an integrated technomanities curriculum fostering the full skillset for value creation.

Assessment

K. F. Yoshino 472-475 Design and Assessment: Theory and Practice

This paper draws parallels between the theories of engineering design and assessment in higher education. Examples of context within which both concepts arose are cited. The paper concludes by arguing that when engineering faculty engage program and classroom assessment, the very principles of engineering design are reinforced.

J. R. Phillips and Z. H. Duron 476-478 Assessment in the Light (?) of ABET Accreditation Criteria

Harvey Mudd College was one of three institutions visited by ABET in 1997/98 as part of the pilot program to aid in the implementation of Criteria 2000. Engineering at Harvey Mudd is non-specialized and characterized by a commitment to design. In particular, it is known for a high-level of student-team project work performed for outside sponsors in the Engineering Clinic. This paper describes assessment activities initiated as a result of our ABET visit. Particular emphasis is placed on those ABET criteria related to design and on our design specific assessment actions. Activities assessed include student presentations, sponsor surveys, and project schedules and budgets.

J. A. Shaeiwitz 479-482 Teaching Design by Integration throughout the Curriculum and Assessing the Curriculum using Design Projects

An excellent paradigm for design education is the integration of design throughout the undergraduate curriculum. The design skills desired of graduates are introduced in the first course and developed throughout the curriculum via projects each semester. These skills are reinforced continuously, and students receive constant feedback regarding their mastery of these skills. The traditional capstone course is used to polish these skills further rather than being the first and/or only place in the curriculum where these skills are taught. Any design project, particularly the capstone project, also provides an excellent assessment measure. After a design project presentation, the question and answer period can be a rich source of assessment information. Students get immediate feedback on their work, and faculty, through questions and follow-up questions, can determine in great detail the level of each student's understanding of and ability to apply fundamental principles. This paradigm also develops oral and written communication skills, provides students the opportunity to develop these skills with periodic feedback, and provides faculty with the opportunity to assess the development of these skills.

P. E. Doepker 483-488 Department Assessment and the Design Course: A Model for Continuous Improvement

The development and implementation of an assessment plan requires input and active participation by faculty and staff at all levels. This paper examines how an assessment infrastructure can be established to provide leadership to an entire university, how continuous improvement can be achieved through the identification of student outcomes and measurement techniques and the role the capstone design experience can play in assessment.

Predicting and assessing student team performance in design projects presents a host of challenges. Most involve turning qualitative interpretations into quantitative assessments. This challenge is simplified when all student teams are working on the same project. Establishing a relative performance metric based on the top and bottom performers simplifies the task. However, in classes where the projects are diverse and/or sponsored by outside industry representatives the challenge is increased. In classes where formalized requirement documentation exists, requirement volatility (change over time) can be used to simplify student team performance assessment, as well as serving as a predictor of future performance on the project. In an analysis based on project requirement documents from the graduate design class at Stanford, ME210, requirement volatility metrics proved to have surprising power as a predictor of student design team performance. Tracked over time, the metric predicted of team rank-order performance. This document will summarize a method for volatility measurement and the results of our initial analysis.