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POSITION PAPER

What we've learned: Design and design centers in engineering education

STEVEN J. FENVES
Department of Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA 15213, U.S.A.
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Abstract

The article is an extended version of the verbal summary presented at the concluding lunch of the workshop on "Computing Futures in Engineering Design." In the paper, the first person is used to differentiate my observations or reactions from the summaries of the speakers' presentations. The common themes that emerge during the workshop are: the need to set the discipline-specific context before computational tools are used; the incompatibilities between point tools that hinder their use; the paramount importance of teamwork; and the need to understand and treat design as a social process.

Keywords: Design Education; Design Centers; Computational Aids; Modelling; Design Processes

1. INTRODUCTION

The workshop focuses on the future roles of computing in doing and teaching engineering design. This report presents a summary of the presentations and discussions, augmented by my personal observations.

In his opening comments, Clive Dym describes design education at Harvey Mudd College and the complementary nature of system modelling using computers and physical modelling provided by the engineering sciences. He stresses that design has been treated as a stepchild of engineering sciences, so that students don't learn the rich languages of design beyond those shared with engineering sciences, that is, mathematics and analytical formulas. His talk sets up several broad themes:

- the role of engineering design education;
- the role of computing in supporting design education;
- the role of computing in design practice;
- the relation between design and analysis in education; and
- the role of design centers.

Reprint requests to: Steven J. Fenves, Department of Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA 15213, U.S.A. Phone: (412) 268-2944; Fax: (412) 268-7813; E-mail: fenves@ce.cmu.edu

The first three themes recurred repeatedly in the panel presentations and in the discussions. The fourth theme surfaced less frequently, but occasionally one sensed a tension between the two elements of engineering education competing for the students time, attention, and problem-solving approaches. The fifth theme did not surface explicitly, probably due to a difference in orientation; while Harvey Mudd College's Center for Design Education addresses undergraduate education, the other centers represented (e.g., Stanford, University of Southern California, Carnegie Mellon) are primarily oriented toward research and graduate education.

2. ON SESSION 1, ADDRESSING MODELS OF THE DESIGN PROCESS

Ray Levitt's talk, "Towards Analysis Tools for the Engineering Process," emphasizes that the foremost task and challenge is to design engineering processes as engineered products. He presents a tool for modelling, simulating, and evaluating design processes on the basis of domain theories, so as to compare expected behavior to desired performance (primarily, time and quality). I expect that such tools will be used routinely for the modelling of engineering process management and that, by analogy to other analysis meth-

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ods, the present capabilities will eventually be extended to critics and redesign advisors.

Stephen Lu and Yan Jin present "Engineering as Collaborative Negotiation," emphasizing that design with customer involvement is a social-technical process, and that information technology tools allow all participants to focus on negotiation of trade-offs. I appreciate two themes particularly: that the scope of design entails the full life cycle of an artifact; and that design rationale is an integral part of the design, not just a byproduct (often not even captured or recorded, much less negotiated). To the list of technical-social processes described, I would add two more: exploration (of alternatives as well as participants viewpoints); and learning by "chunking" design episodes for reuse.

Steve Lukasik speaks about "Systems, Systems of Systems, and the Education of Engineers," based on his experience at DARPA and TRW, among others. He emphasizes that systems of systems acquire their own behavior, distinct from that of the constituent systems. Lukasik presents suggestions on how students (and faculty) may learn more about the phenomenology of systems of systems, particularly systems not designed to work with other systems. My sense is that software is a good place to start: every student "linking" two "packages" soon experiences the problem.

Patrick Little, in "Project Management and Management of Design: Teaching and Tools," addresses the dearth of education in design management and the lack of tools supporting design management (as opposed to tools such as the critical path method for project management). He identified iteration, often nested, as one of the key features of the design process. I think Ray Levitt presents the broader issue: before a design process can be managed, it has to be designed; iterations due to miscommunication can be "designed out" and iterations representing progressive refinements or spiraling-out can be "designed in."

The lively discussion centers mainly on the taxonomy of design problems (e.g., routine vs. innovative) and the levels of support they require, and on cultural issues when designers (and clients) are more tightly integrated and designers must do more than their "traditional" job to facilitate the overall process.

3. ON SESSION 2, ADDRESSING THE USE OF COMPUTERS IN DESIGN PRACTICE

Louis Komzsik, speaking about "Meshless Finite Element Analysis: A Fallacy or Reality," describes the commercial demand for separating form (geometry) and function (strength, etc.) design to the point where the designer deals with geometry only, and the functional analysis tool does the meshing as well as the analysis. Komzsik describes the current state-of-the-art, which is not yet close to this scenario. The talk raises the important question of what should be taught about behavior. I have some further questions: except for the simplest components, can all form design issues by fully dealt with before physical function and behavior is addressed? Furthermore, is there a role for proactive functional design, where the form is derived so as to achieve a desired physical function?

David Wilson speaks about "Data Exchange and Software Integration: Interdisciplinary Design Challenges," highlighting the problems of interoperability of disparate, domain-specific tools for circuit simulation, electromagnetic simulation and mechanical function analysis. He emphasizes the need for models that mirror the engineers thought processes and sketched aspects of future shared workspaces that can support "remote site interdisciplinary co-creation." In my opinion, this talk gives a concrete manifestation of Lukasik's concerns about systems comprised of systems that have not been designed to work together, and poses some of the problems facing component designers and integrators.

Twila Hart Humphrey presents a talk on "Engineering Process and Tool Integration," resulting from process reengineering and supporting Integrated Product Teams. The support infrastructure is built around a single 3D master model database and an integrated set of design analysis tools, allowing the teams to "understand what the customer wants and deliver it flawlessly." My reaction is that this presentation answers a large portion of the concerns raised by Levitt, Lu, Lukasik, and Wilson, and shows all of us a glimpse of the future in computer-aided engineering. The presentation also gives a sobering sense of the sheer magnitude of the support infrastructure needed to realize process and tool integration.

The discussion that follows covers educational implications, issues of design team composition, culture and management, and database issues of stability, heterogeneity, etc. As in Session 1, the need to record design rationale is emphasized as the primary means of communicating and negotiating interdisciplinary aspects of design.

4. ON SESSION 3, BILLED AS "THE ROLE OF TECHNOLOGY IN DELIVERING EDUCATION" AND COVERS A NUMBER OF RELATED ISSUES

Jim Garrett speaks on "The Computer-Aided Engineer: Prospects and Risks," providing a link between the two sessions by elaborating on the active and adaptive design support systems needed to assist designers who are designers because they like to design. He emphasizes three needs: dual-use representations understandable by the designer as well as being computable; support in the navigation of complex and large design spaces; and avoidance of cognitive overload on the designer. I believe that these needs embody the functional requirements for future design support systems and for the education of designers.

Bill Spillers, in speaking of "The Future of Computers and the Teaching of Engineering Design," raises questions of what the engineer should know, what aspects of design

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should be automated, and what constitutes support for creative designers. Clearly, the engineer doesn't need to know all the innards of a program to use it. I believe that Spillers' concern that "anything that can be automated will be" no longer holds; as most of the workshop speakers stress, the primary issue today is appropriate level of support, rather than replacement, of designers by information technologies.

Jim Rosenberg talks about "Stimulating Appropriate Use of Simulation in Design." He stresses that formal design methods are applicable when there are well-formed goals and accepted evaluation metrics. Most designs start with much more limited information about goals, criteria, constraints, etc. To rapidly configure such designs, simulations of detailed behavior are needed. He stresses the need for teaching simulation: when to use it; how it relates to closed-form models; and how to select from a hierarchy of tools. In my opinion, this recommendation is one step toward answering the perennial question of what the student should learn or know about an engineering science topic: the theoretical basis, a "closed form" application of it (no matter how limited in scope); and a means to simulate it for more complex applications.

Dan Rehak's talk is entitled "From Ivory Towers to Ethereal Webs: Educational Directions for the Information Age." He demonstrates aspects of education delivery using a variety of off-the-shelf tools and components, and then goes on to speculate on the impact of the emerging tools on the nature of education and of the universities themselves. Just as industry has moved from batch production to "economic delivery in lot size of one," education will increasingly move to "custom" design. I agree with his predictions, but I am heartened by it; engineering designers who have embraced information technology have a lot to contribute to the design of new systems of education. Furthermore, our episodical attention to what the student should know will have to become much more focused and intentional in the new educational environment.

The discussion deals with approaches to active learning, the applicability of the new media to large-scale problems, the role of social interactions in the learning process, and the new demands on information technology support: outcome assessment; navigation through multiple sources of knowledge; and modularization of learning material.

5. ON SESSION 4, DEVOTED TO "WHAT IS LEARNING?"

Jack Appleman's talk is entitled "Mind versus Machine: The Uncertain Future of Human Thoughtworks." He describes several software system design projects that illustrate the learning that takes place while designing: searching large, dynamic design spaces and using analogy and intuition in formulating the "real" problem the client needs to have addressed. I appreciated his emphasis that design is not an analytic venture, and that it requires synthesis of many sources in the formulation and in the implementation and evaluation of the solution.

Mary Williams (and Bill Purves in absentia), in "Computers and Learning" introduced an educational setting based on a goal-based scenario where students learn by working realistic problems. I agree with her definition that real learning takes place when the knowledge acquired is internalized and operationalized by the learner. However, I question her thesis that realistic problems have to be "impossible."

Renate Fruchter speaks about "Roles of Computing in P^5BL: Problem-, Project-, Product-, Process-, and People-Based Learning." She emphasizes the threefold learning task in team design education: exercise acquired theoretical knowledge; understand relationship to the broader context; and participate in the team, eventually to lead it. I particularly appreciate her comments about the need to adopt and adapt technologies to achieve the desired learning support environments.

Sheri Sheppard and Larry Leifer present "Reality Brings Excitement to Engineering Education." They emphasize the need for technologies supporting various levels of design education, stressing physical hardware and multimedia support. They describe their continuous efforts to monitor, adjust, and transform the learning process. I believe that their work is a major step toward the development of a process model of engineering design education and learning.

The discussion, not surprisingly, centers on two issues: evaluation methods and metrics of learning; and efficiency and effectiveness of information technologies in delivering education and enabling learning.

6. CONCLUSIONS AND GENERAL OBSERVATIONS

First, true to the setting of a small engineering college stressing breadth, the interaction of a small group was most beneficial in raising the issues involved (without necessarily solving any of them). In the same vein, the specific discipline of a particular speaker is largely irrelevant, while most of the attendees were civil and mechanical engineers, everyone understands the interoperability problems in electromagnetics discussed by David Wilson and the goal-based educational scenarios in biology presented by Mary Wilson.

Second, the paramount importance of teamwork is a constant theme: its formalization and modelling in Session 1; its role in the practice of design in Session 2; and its contribution to learning in Session 4. This repeated emphasis leads me to question whether in the educational process teamwork can be relegated to design and project courses only, as it is currently done at most universities, and whether some components of our analysis courses should also be conducted on a team basis.

Third, and closely related to the previous one, is the repeated emphasis on design as a social process. It is clear from most of the presentations and discussions that the task at hand is not that of developing design theory and methodology to the point where it takes its place along mechanics, thermodynamics, etc. in the engineering curriculum.

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Rather, the task is to understand the social processes that take place during design, to provide meaningful immersion in these processes for our students, and to develop tools that foster, rather than inhibit, these processes.

Finally, we revisited many trends in industry: from batch production to economic customization; from "islands of automation" to increased integration; and from fixed I/O black-box tools to flexible, transparent, and adaptable ones. Several speakers stress that the biggest impediments to those moves is not the lack of enabling technologies but the mindset of the people based on their previous education and training and the inertia caused by existing, legacy systems. Dan Rehak raised the sobering prospect that academia may be following industry, and that the batch delivery of graduates may be replaced by a customized delivery system analogous to industry. Thus, in addressing the future of computing in engineering design, we have to add one more theme to the ones initiated by Clive's opening comments: the role of computing and design education in re-engineering the educational process itself.

Steven J. Fenves is University Professor of Civil and Environmental Engineering at Carnegie Mellon University. He received his B.S., M.S., and Ph.D. degrees in Civil Engineering from the University of Illinois. His technical interests include computer-aided engineering, conceptual design aids, representation and processing of design standards and regulations, engineering databases, and applications of artificial intelligence and machine learning in design. He is a member of the National Academy of Engineering and Honorary Member of the American Society of Civil Engineers.