Bridging the Gap Between Education and Practice in the Design and Development of Engineering Systems

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Abstract - In this essay, I focus on the challenge of educating our engineering students to be successful and ready to face the challenges posed in product design and development problems they will face in industry. I am concerned with design beyond just component design and design process courses. I am focusing on the design of systems; systems that are designed, developed, manufactured, and produced. I first propose the challenge and then discuss my response to this challenge by detailing my educational philosophy and specific initiatives I am undertaking.

The Challenge
In a National Research Council report [1], it was recognized that weaknesses in design capabilities have become a factor in the decline of the U.S. competitiveness. The American Society of Mechanical Engineers (ASME) report on "Integrating the Product Realization Process (PRP) into the Undergraduate Curriculum", reasserted that these weaknesses in U.S. companies are a crucial factor in the decline of the nation’s international competitiveness [2]. As companies become more and more aware of their design deficiencies, they are beginning to look more towards U.S. universities to provide the proper education and training for engineers. The problem of effectively educating our engineering students to be able to contribute and compete successfully in a dynamic marketplace in times of constant change is a challenge that faces all engineering educators.

With the educational initiatives and programs I am developing, I address four of the key areas identified in the American Society of Mechanical Engineers report on education in product realization [2], namely,

1) **Knowledge of Product Realization Processes (PRP):** concurrent engineering, business functions, corporate vision and product fit,
2) **PRP Team Skills:** project management tools, budgeting, design reviews, communication, leadership, conflict management, and teams/teambuilding,
3) **Design Skills:** competitive analysis, creative thinking, systems perspective, design for cost, design for performance, and CAD systems,
4) **Analysis and Testing Skills:** value engineering, statistics, product testing, testing standards

Edward de Bono [3] states that we have come to the end of the Euclidean age of thinking, where the universe was assumed to be static. The end of the age of the closed problem is upon us. We face the dawn of an age of open, complex, and dynamic problems that require correlated and concurrent thought. It is these types of problems that excite me from an educational perspective. As many students voiced in my graduate design course last semester, they enjoy and get much more benefit from open problems that have many possible solutions. This is exactly the type of problem they will face in industry: dynamic, ambiguous problems that may not be well-defined, may have multiple measures of merit, combine information from multiple disciplines, and require rational and sound decision making. Effectively educating students to handle these types of design problems with competence, confidence, and success is a challenge I am dedicated to tackling.

The Response
It has been said that, “In theory, theory and practice are the same, but in practice, theory and practice are different.” As a starting point to address the challenges in system design education, I would like to work towards dispelling this common assumption which has been a barrier between academia, industry and government. My experience in industry, university, and government research labs has helped me appreciate the needs and possible benefits of future collaborations. I strongly believe that there should be a balance between **theory** and **practice** in engineering education. In other words, in my opinion engineering education, and in turn engineers, should balance **reality** and **fantasy**. Reality is the fundamental engineering theory and physical laws, while fantasy is the creativity, openness, and intuition always present in design. Design engineers should be able to balance creativity and laws of nature, reality and fantasy, theory and practice. To foster this mindset, engineering education should be a balance as well.
I feel that a systems perspective to education can be taken to tackle these challenges presented. In systems thinking, one not only sees the individual entities, but also the interfaces among them. Senge defines systems thinking as follows [4]:

“The essence of the discipline of systems thinking lies in a shift of mind:
• seeing interrelationships rather than linear cause-effect chains, and
• seeing processes of change rather than snapshots.”

One realization of systems thinking in education is a perspective of not only the product being designed, but the processes that are required to design it as part of the overall product realization system. Therefore, in the ideas presented in the following, I focus on the entire enterprise of designing and producing products, processes, and systems. I outline some initiatives I am currently involved in that are aimed at improving the efficacy of our engineering educational institutions.

**Graduate Course Development**

No two students, like any two systems, are alike. So, why should they all be educated the same? Some respond strongly to visual forms of information, while others get more from verbal forms. Some prefer interactive learning, while other are better learning individually [5]. This is the approach I took in the graduate course I recently developed ‘Design of Complex Engineering Systems.’ In the final assignment of this class, the students are asked to design the entire course structure and classroom. Although a university course is not an engineering system, it is a dynamic system that is constantly being designed by professors in many different ways, some effective, others not. I wanted to learn first hand what the students learned about designing systems and how a course and classroom can be designed and structured to maximize the educational benefit.

The starting point was to view the classroom itself as a system and designed not only the physical layout of the classroom, but also how the students and teacher(s) interact, what type of measures of progress are used (assignments, tests, discussions, presentations, etc.), and what kind of medium of transmission is used. Some interesting insights were gained:

- With the advent of multimedia technologies, of which I used at times throughout the semester, I expected the students to be unanimous with their responses to how should the information be transmitted. Supporting the inherent difficulty in engineering educators’ jobs, some students prefer the traditional chalkboard, some prefer handouts, some prefer overhead projection, and others prefer the use of multimedia.

- I also received many different physical layouts of the classroom, ranging from a classical professor standing up in front of rows of seats to a three-tiered rotating classroom with three different professors addressing different perspectives of the same topic area.

- The one constant that the students voiced is their preference for dynamic problems that have more than one solution. Closed, textbook problems, they claimed, are not the most effective learning mechanism.

Even though their designs and insights were quite varied, it was obvious that the students are concerned with their education and how the receive it. They raised many valuable issues that I would have never known if not for this exercise. Treating the classroom as a system is a valuable approach, I truly believe.

In the written anonymous feedback the department receives from the students after the course, the most telling response was from one of the undergraduates who was taking this graduate course. He said, “This class is a definite MUST for undergraduate students.” Catering the course to the individual students’ needs, allowing for open discussion and exploration, and letting the students have a sense of control and responsibility for the progress and structure of the class proved to generate great excitement and learning for both the students and myself.

Another class I am developing is, ‘Design Methodologies’, where various approaches to design will be studied, contrasted, and compared. Topics such as optimization and utility theory, which are useful tools in engineering design but typically separated in education, will be integrated. Practical issues, such as the presence of multiple measures of merit, discrete and continuous variables, and satisficing vs. optimizing will be addressed using real world design problems. Industry involvement will be included. Commitments have been made by Xerox, Allison/Rolls-Royce Engine Company, and Praxair to provide practical case studies and lectures. By handling and modeling these issues (establishing the synergy between design and engineering), designers can benefit greatly in decision-making effectiveness.

**Developing an Undergraduate Virtual Design Corporation**

From an educational perspective, systems thinking takes the form of bridging gaps among courses, so that students
do not see a curriculum as 32 isolated courses, but perhaps rather as subject modules with some number of related components. I am the principal investigator on a proposed project combining faculty from the Department of Mechanical and Aerospace Engineering at the University at Buffalo (UB) and the Department of Technology at Buffalo State College to develop a virtual aircraft design corporation that would uniquely provide both vertical and horizontal curriculum integration by involving students from a number of courses ranging from the freshman through senior years. The program involves setting up the corporate structure with a Board of Directors (project PI’s), and Advisory Board (Calspan Flight Research, our industrial partner), a CEO and Vice-President (the graduate Teaching Assistants), and a number of Product Development Teams (teams of undergraduate students from a number of different courses from the freshman through the senior level). The course will be coordinated primarily on the internet using email and a website to provide a mechanism for collaboration among the teams of students from the various courses and campuses. At the end of the semester, the students will actually test out their aircraft design using the Flight Research Simulator at Calspan Flight Research to gain a practical experience of seeing the success or failure of their work. Instead of just getting a grade and some comments from their instructor, the students will be able to actually see and feel their product either work or fail and will get real-time feedback in an industrial environment where success or failure will mean profit or possible bankruptcy, as opposed to just an ‘A’ or ‘C’. This project will address many problem characteristics that is lacking now in most of the present engineering education: teaming, communication (both within and across courses), open problem with multiple solutions, closed-loop implementation with industrial partner, and corporate environment. This project will provide a close loop large-scale design experience which is largely lacking in undergraduate mechanical and aerospace engineering programs.

In the ASME report, the second and third ranking practices (out of fifty-six) that were identified by industries to be crucial to graduating engineers success are communication and teams/teamwork, respectively. These are precisely two of the practices we will be stressing in this project. Not only will each student be on a team in a given class, but their disciplinary team will also part of a larger product development group of teams. Therefore, the students will be involved in a teaming project in a given class, but will have to be skilled at communication across boundaries between classes as well. This communication and holistic approach to engineering is what we feel (as does U.S. industry) to be lacking at the undergraduate education level presently.

Another primary motive in this project is the notion of ambiguity vs. certainty. For example, in traditional analysis-based courses, there usually exists one solution to a closed problem from a textbook. Either a student is right or wrong. But this approach does not teach our students the ability to handle open, new problems where a number of solutions may exist. In this project, teams will attack similar problems and may come up with different solutions. They will have to handle ambiguity, incomplete information, limited resources—characteristics of practical industrial engineering problems. At a time when ABET is now stressing ‘outcomes’ as their measurement standard, I feel the outcome of our curriculum (quality of our students) will increase dramatically through this program. The students will be exposed to practical, large-scale engineering problems throughout their academic career (vertical and horizontal integration) that cannot be solved by one person (teaming), and that necessitate interaction (communication and collaboration).

**Continuing Education**

In response to the needs of U.S. industries, I am leading an effort in the Department of Mechanical and Aerospace Engineering (MAE) in the School of Engineering and Applied Sciences (SEAS) to create an advanced certificate program in ‘Product Design and Development’ that directly addresses the types of skills that design engineers must have to enable their companies to succeed in the global marketplace. This certificate has been structured to provide advanced training and education for practicing design engineers who may not want (or have the time) to pursue a graduate degree. Each person completing the certificate requirements will be officially sanctioned by the State of New York as having achieved education and specialization in product design and development beyond an undergraduate degree. In the present market, design engineers must have the analysis and synthesis skills, as well as the people skills, to be able to handle open, complex problems that companies face when designing, manufacturing, producing, and/or supporting their products or services. These skills will be some of the primary educational thrusts in the certificate program.

**Closure**

To close this essay, I provide some of my observations that have shaped my philosophy on the role of professors and on who I aspire to be:

- I subscribe to the notion of learning through doing. I believe that true understanding of principles occurs when one is really applying them.
The "monkey see, monkey do" paradigm is effective for recipe-based approaches to sets of similar closed problems. However, with open problems in engineering design, knowledge is created only when the student knows how to learn, and can understand and internalize problem-independent principles.

• I believe engineers, in order to be successful in a competitive society, must never stop learning and educating themselves both in depth and breadth. I provide the students the chance to think and internalize the skills they are taught so that they can use them in their future learning processes. I let students learn that the systematic approaches taught in a design class can be used not only for designing a good product or process but also for designing a better society and a better life.

I look forward to tackling this challenge and many others over the coming years as an educator in engineering, as there is still no substitute for being there when a student finally understands a fundamental principle, develops and supports an original idea, or just wants to chat with you about design, engineering, and life.

References