Integrating Creative Problem Solving and Engineering Design

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Abstract

"Engineering design is the communication of a set of rational decisions obtained with creative problem solving for accomplishing certain stated objectives within prescribed constraints." How can engineering design be taught within the framework of this definition—what are the goals and building blocks? An innovative textbook demonstrates an integrated approach usable at the freshman and senior levels and for multi-level, mutidisciplinary projects. The textbook will be published by mid-June through McGraw-Hill's College Custom Series. The paper will describe the approach and discuss experiences with different parts of the course content. By conference time, additional feedback from senior projects in technology will be available.

The integrated approach has a double focus:

- Develop the required thinking skills: visualization, cognitive models, communication, teamwork, and creative problem solving. Industry as well as the ABET 2000 Criteria demand that engineers have these foundational skills.
- Apply the skills in the twelve steps to quality by design. The textbook provides many practical "how to" guidelines, planning and economic analysis tool templates (attached on a CD-ROM), and a library of design documentation samples to enable instructors and students to focus on optimizing their design projects and solutions and prevent dysfunctional teams.

A teaching manual accompanies the textbook and will be available from a web site. It includes sample syllabi for a variety of courses from pre-college programs and freshman engineering orientation to senior capstone design and workshops to enhance creativity and innovation in the workplace. This broad range is possible by shifting the emphasis from learning the process of creative problem solving to achieving a quality design product. Also, the textbook is built on the knowledge creation cycle and thus addresses different thinking preferences and learning styles. Formats range from 15-hour course modules or seminars to quarter or semester courses or sequences.

Motivation

The purpose of this integrated textbook is to enable engineers and technologists to be more innovative in conceptual design. This book has a strong focus on creative thinking and problem solving, visualization, teamwork, and communication. It responds to the needs of industry for employees who have these foundational skills needed for concurrent engineering and to the ABET Criteria 2000 (which require that engineering and technology students are able to work on multidisciplinary teams and understand the global context of their work). The unique integrated approach enables students to not just learn the fundamental principles and thinking skills but to apply them in the design process to achieve optimum solutions and, ultimately, to become innovators.

This book evolved from an earlier work, *Creative Problem Solving: Thinking Skills for a Changing World.*[1] Through feedback from users and from observing trends in engineering design education, we sensed a need to *explicitly* show the application of creative problem solving to engineering design. The creative problem solving process can be used (and has been applied) in many different personal and professional areas. Engineering design has been taught—albeit predominantly in a procedural, analytical fashion—for many years; it can be, but unfortunately it seldomly is, synonymous with creative problem solving. What we have attempted with the new book is to integrate the two approaches into a unified system which focuses on developing conceptual designs and then synthesizing an optimum solution. We found that this system can be applied in a variety of classes for many different levels of students (as will be explained in this paper). Skeptics have said that this couldn't be done, since textbooks are commonly written for a specific level of students. Thus our approach represents a new paradigm.

To instructors and students alike, the book is both challenging and user-friendly. At each step, we asked what tools and techniques we could provide to make learning and engineering design easier, more effective, and of higher quality. For example, we found that students had difficulties applying what they were learning in engineering economics to their design projects; thus a custom-designed software program COMPARE—in a simple data entry and calculation sheet format—allows students and engineers in industry to evaluate design concept alternatives (including complex systems). We show how to apply Microsoft Project 98™ to planning a team design project, and a complete set of two dozen design documentation formats includes written reports, verbal presentations, and a range of drawings meeting different purposes.

We have adopted a format and style that is easy to read. The book is not tied to any specific design software but is particularly suited for integration with solid modelers which require "different" thinking skills. Because—in collaborative learning—students teach each other, many teaching (and facilitator) guidelines are included in the text. Each chapter is basically structured on the knowledge creation cycle[2] (which in turn builds on the Herrmann model of thinking preferences[3]). A separate teaching manual will be available from **www.engineering-creativity.com**. It will provide additional teaching hints and hardcopy for overhead transparencies, as well as examples of handouts. The discussions of class activities and possible outcomes of homework assignments suitable for different levels of students will be accessible with a password given to instructors.

Overview and Concepts

The role of design has been debated in many circles during the 1990, especially as it relates to restructuring of the engineering curriculum in response to changing technology and globalization of the workplace. But whether this restructuring takes the form of a completely integrated curriculum (as articulated for example by Joseph Bordogna, former dean of engineering at the University of Pennsylvania[4]) or more conservatively by making only minor adjustments by such means as introducing more interdisciplinary design courses, the design methodologies used overwhelmingly emphasize an analytical approach.[5] The underlying assumption seems to be that students would learn the necessary thinking skills for creativity, teamwork, and communication if they participate in a semester- or year-long design project or if the curriculum contained a certain number of hours of design content. The end result is that industry has been spending millions of dollars teaching their employees the foundational skills (such as creative thinking and teaming) needed for innovative conceptual design and problem solving in a global context.

Our vision was to address this need by teaching these skills explicitly and then integrating them explicitly into the design process. Our aim was to demonstrate how creative problem solving, teamwork, and effective communication skills can be taught concurrently—or integrated—with teaching design. Thus the focus in Part 1 of our book is on the fundamental thinking skills. Then in Part 2, students learn the creative problem solving process, where the steps are immediately applied to a design project, with the design perspective, steps, and tools provided in detail in Part 3. This three-pronged approach provides tremendous flexibility in how individual instructors are able to apply these principles in their courses. Table 1 gives an overview of how a change in emphasis from Part 2 (Creative Problem Solving) to Part 3 (Engineering Design) meets the instructional needs for different levels of students, from pre-college to the industrial workplace. Note that Part 2 and Part 3 are integrated and are to be taught concurrently, as shown in Figure 1 and discussed in the following section.

Table 1 Change in Emphasis for Teaching Different Levels of Students

Creative Problem Solving	**Conceptual Engineering Design**
Pre-College Programs	
Freshmen: Intro to Engineering	
Multidisciplinary Creative Problem Solving	
Multilevel Design Competitions/Projects	
	Senior Capstone Design
— — — — — — — — — — —	Workshops in Industry

The book models the integration of creative problem solving into conceptual engineering design. There are many excellent engineering design methodology books on the market[6]; we do not claim to substitute for their rigorous treatment of the subject. What we offer is something extra—with our book, instructors are able to make effective use of teamwork, encourage creative thinking, enhance the quality of design documentation and communication produced by the students, and most of all help them learn the skills that will enable them to innovate in the workplace. Interestingly enough, the ABET Criteria 2000 do not mention innovation. We see the ABET criteria as a set of minimum "standards"—not as goals—thus our book goes beyond those target outcomes.

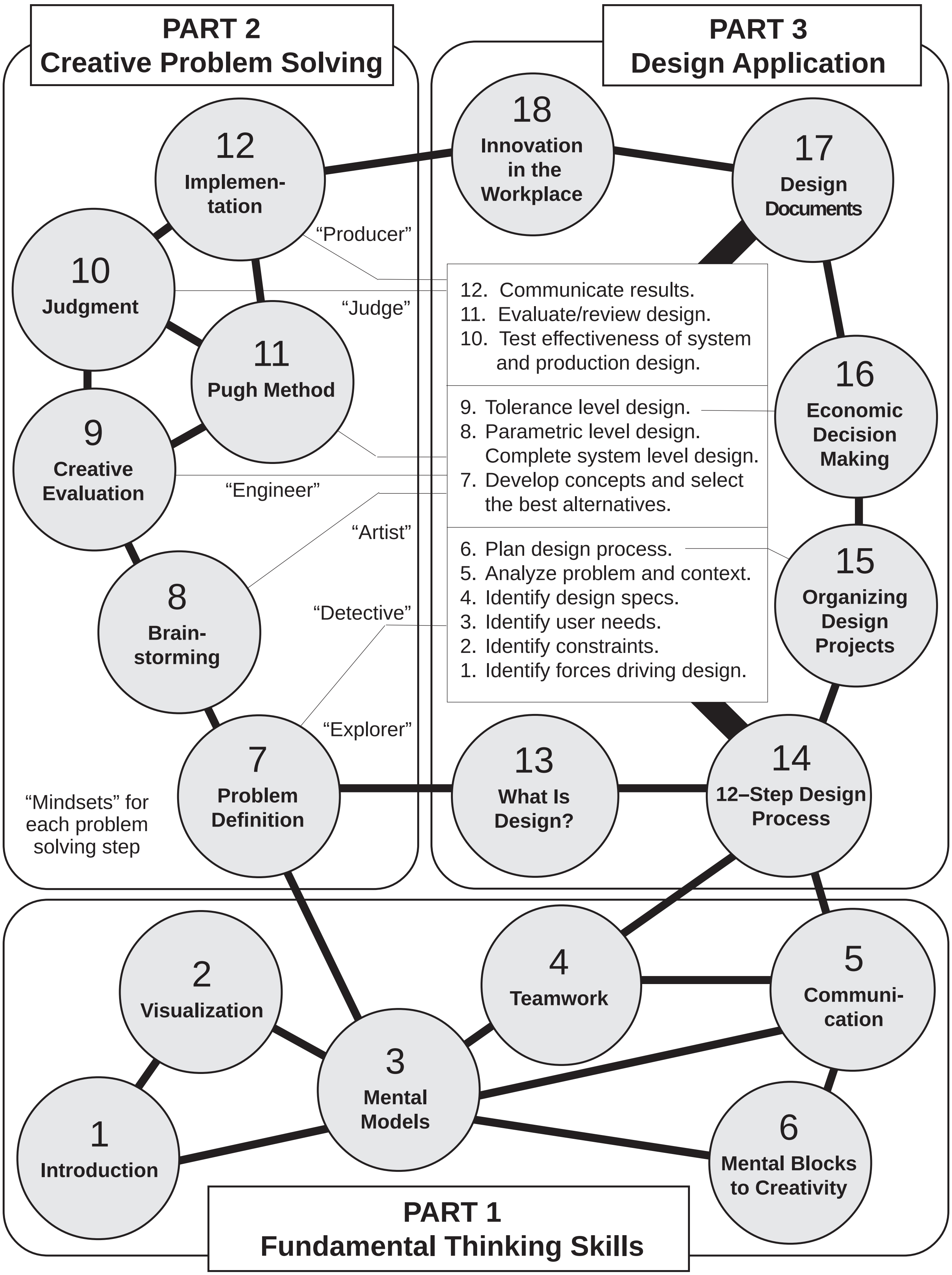

Figure 1 Chapter integration of thinking skills, creative problem solving, and engineering design.

Let us use an analogy. When we learned calculus in the 1960's, we spent hours painstakingly plotting curves and intersecting surfaces, and even then it was difficult to visualize what really happened (in physical terms) when parameters in equations were changed. Today, with a touch of a button or two, students can visualize much more complicated equations in an instant; they can play around with changing different parameters and thus gain a much deeper understanding of what the equations (and their parameters) signify. Once students master the fundamental thinking skills (listed in Table 2), they will be free to concentrate on the process and outcome of design—they will not be sidetracked by the mechanics of "plotting"—their minds will be able to function in the desired mode "at the mention of a particular metaphor." Depending on the level of the students, all of these topics need to be covered (either in depth or as a review). They address the ultimate goal in industry —> the ability to innovate for global competitiveness.

Table 2 Content of Part 1: Fundamental Skills and Mental Models
1. Introduction: The bottom line—how to succeed in the rapidly changing world of the 21st century. The global context (including ABET and industry needs). Definition of important concepts: creativity, problem solving, and paradigm shift. Hints for effective learning.
2. Visualization: Memory and the brain. Four mental languages. Four visualization techniques to enhance memory. Sketching, a tool for conceptual thinking. Visualization and solid modeling.
3. Mental Models: The Herrmann brain dominance model and its application to engineering design. The knowledge creation model. The creative problem solving model and its associated metaphorical mindsets.
4. Teamwork: Definition, advantages, and disadvantages. Team development. Functional and dysfunctional teams. Team management guidelines. How to form whole-brain (multifunctional) project teams. Tools for organizing and managing a team for productivity.
5. Communications: Verbal communications and teamwork. Two practical tools: the 30-second message and principled negotiation. Communication in engineering design—introducing a complete dossier of 24 formats for written documentation and verbal presentations needed for a design project.
6. Mental Blocks: Removing "false assumptions" barriers. Removing "habit" barriers. Removing "attitude" barriers. Encouraging creative thinking. Review of Part 1.

Integration of Creative Problem Solving and Design

"Engineering design is the communication of a set of rational decisions obtained with creative problem solving for accomplishing certain stated objectives within prescribed constraints." Part 2 and Part 3 of the textbook are driven by this guiding definition. Although creative problem solving and engineering design are presented in two separate parts of the textbook, they are to be taught concurrently, but proportionately with a different emphasis, as illustrated in Table 1 for different types of courses and levels of students. This is the unique systems approach that enables instructors to develop different course syllabi using the same book. Table 3 describes the contents of Part 2, Table 4 the contents of Part 3. An extensive appendix contains descriptions of analytical

Table 3 Content of Part 2: Creative Problem Solving
7. Problem Definition: Objectives. The "explorer" for divergent thinking—looking at the context and trends. The "detective" for convergent thinking—obtaining customer data, analyzing the problem, and planning the project. Guidelines for a hands-on team project.
8. Idea Generation: The role of the "artist." Planning and leading a verbal brainstorming session. Other brainstorming methods. What to do when you are stuck. Examples and directions for continuing the team project.
9. Creative Evaluation: The role of the "engineer." The creative idea evaluation process. Examples and directions for continuing the team project.
10. Idea Judgment: The role of the "judge." What is good judgment? Critical thinking. Ranking different options. Decision making. Directions for continuing the team project.
11. The Pugh Method: The product development process. Economic benefits. The Pugh evaluation process for conceptual ideas. Application examples.
12. Solution Implementation: The role of the "producer." Selling ideas. The work plan and implementation. Monitoring and final project evaluation. Time management. Review.

Table 4 Content of Part 3: Application to Conceptual Engineering Design
13. What Is Engineering Design? Definition and implications: users and customers, products, processes, systems, ethics, and stewardship. Using Part 3 as a curriculum guide.
14. The Engineering Design Process: Twelve steps to quality by design. Design problem analysis stage. System (concept) level design stage. Parameter level design stage. Tolerance (detail) level design stage. Design evaluation stage. Guidelines for using a modified version of the Pugh method for student projects. Student assignments.
15. Project Planning: Guidelines and templates included on a CD-ROM for using a practical planning tool for team projects (specifically Microsoft Project 98™).
16. Economic Decision Making in Engineering Design: Guidelines and templates for using a new and practical program (COMPARE) included on a CD-ROM (based on Excel™). This tool allows the evaluation of design alternatives based on system and life-cycle cost, cash flow, and other accounting methods in a simple data entry and calculation format.
17. Design Documentation: Samples of two dozen oral, written, and graphical design documents and presentations needed for a complete design project.
18. Innovation in the Workplace: Prerequisites for organizational innovation. Who are the innovators? Four pillars for overcoming barriers and sustaining innovation in an organization. Checklist for identifying a creative organization. Conclusion.

problem solving methods used in industry (QFD, Benchmarking, SPC, FMEA, FTA) as well as summaries of TQM and the Kolb model of learning styles. The lower-level courses focus on learning the process—the outcome is incidental and students are shown how they can learn from "failures." For advanced students, the focus shifts to the design project outcomes; it is assumed that they have mastered the foundational thinking tools, and the quality of the conceptual designs within the context of effective teamwork becomes paramount. Figure 1 depicts the relationship of the three parts of the book and the integration between the creative problem solving chapters and the topics in the design application chapters.

The teaching manual includes seven different syllabi to illustrate how the book's unique structure makes it usable for many different classes and class formats—from a year-long two-semester sequences to quarter courses and 15-hour "just-in-time" modules focusing on specific topics. Also included are supplementary materials that might be of interest to instructors, such as the Perry model of critical thinking and whole-brain mindmapping. We are in the process of developing a web site where instructors can network, exchange information, ask questions, and display student projects, as well as download the Teaching Manual (with the "answer" portions accessible only with a password).

Experience and Feedback

1. Integration into Existing Curricula at Michigan Tech: Creative problem solving was made a required freshman course in electrical engineering at Michigan Tech from 1994 to 1998. In its current curriculum restructuring effort, the department has developed its own Introduction to Engineering course, as well as a senior professional design laboratory. Both stress teamwork and communication skills. The existing Creative Problem Solving course GN150 (a requirement in general engineering and a technical elective for all other students) has switched to a stronger focus for the design project, since the student teams invent exhibits for the Keweenaw Children's Museum now under development. In 2000, the university will switch from a quarter to a semester system; simultaneously, curriculum restructuring is also taking place, and a change to a common first year for all engineering students is envisioned. To what extent the introductory engineering sequence will incorporate conceptual design and creative problem solving, teaming, and communication skills has not yet been determined. Recently, a proposal was submitted for the development of five "just-in-time" 15-hour modules for the Engineering Enterprise program funded by NSF—these modules can teach the book's content in a very flexible format distributed over the four years of a typical engineering curriculum. A grant from the National Collegiate Inventors and Innovators Alliance will allow for prototype construction of projects developed by student E-teams in a new "invention and entrepreneuring" course or as special problems.

2. Use of the HBDI in Engineering Courses: The use of the HBDI (Herrmann Brain Dominance Instrument) as a team and synergy-building tool in a freshman course at the University of North Carolina at Charlotte was documented in two ASEE publications.[7,8] Student responses to the usefulness of the HBDI in team projects on conceptual design have been very positive, and all freshmen engineering and computer science students now complete the HBDI as a part of their Introduction to Engineering course. At Michigan Tech, the HBDI is used for forming optimum "whole-brain" teams in electrical engineering orientation, GN150, and some ME courses.

3. Use of Communication Formats and Templates as Project Guides at UNCC: Earlier versions of the document formats (compiled in Chapter 17 of the new book) have been used in senior design project courses at UNCC for ten years or more. Typically, students at first see documents such as proposals, project plans, project concept statements, specifications, project objectives, progress reports, etc., as "paperwork" requirements that hinder their progress toward the "real" design work. As the semester progresses, however, many students begin to see advantages in this organized, sequential approach to design as communication. Instructors coach students to see the completion of each document as the product of an essential step in the design process as well as a material part of the final report. Frequently, students completing these capstone courses comment on their appreciation for the process which assisted them in achieving a satisfying project and producing a report which they see as valuable to show prospective employers.

4. Senior Capstone Design in Technology—Piloting the New Book at UNCC: An early version of the book was used by Professor Edwin R. Braun with a small group of technology students in 1998. He is now piloting the final draft of the book with about 50 students during the spring semester 1999. We are planning a detailed questionnaire to collect feedback from the students (and instructor) about the book on what worked and what could be further improved. Professor Braun will join us in presenting the results at the ASEE conference.

5. Teaching Creative Problem Solving—Middle-School Students to Professionals: Because the creative problem solving process consists of definite steps involving fundamental thinking skills and principles, the teaching of the process is adaptable to a broad range of students and multidisciplinary classes. We have successfully taught it in a program involving middle school students from inner-city, suburban, and private schools (and their parents), thus bringing people from many different economic and cultural backgrounds together.[9] Also, we have taught numerous two- and three-day creative problem solving workshops in industry and to engineering faculty in the U.S. and abroad. Other senior and graduate level applications we have heard about have been in teacher education and business management.

6. Feedback from Students: Based on past results and student comments, we feel that this creative, integrated approach will help attract or retain underrepresented minority and female students, as well as the more creative students in engineering—traditionally, these "different" students have tended to drop out of engineering at a much higher rate than their more analytical peers.[10,11]

Conclusion

Based on our experiences with major portions and approaches used in the new book, we believe that this text offers substantial potential for use in the following applications:

- ❏ Introductory engineering courses stressing the development of team skills and/or conceptual design.
- ❏ Disciplinary project courses.
- ❏ Engineering design project courses.
- ❏ Multidisciplinary capstone courses or projects in industry.
- ❏ Creative problem solving courses, seminars, and workshops.
- ❏ Modules on teamwork, communications, innovation, and other topics.

The text contains examples of assignment sets for (a) a one-semester freshman course, (b) a one- or two-semester capstone design project, and (c) a vertically integrated, mutidisciplinary design course. Other course assignment sets may be created by selecting from the examples in Chapter 17—the design document "library" of the text. Auxiliary uses are in pre-college programs and teacher workshops, as well as in undergraduate and graduate courses in engineering management, education, and communication.

Looking at a broader context, just over this past year we have noticed a strong increase in interest in the teaching of creative thinking and innovation inside and outside of engineering. For example, Singapore has mandated the teaching of creativity, and the government is funding a large Innovation Centre. Taiwan, Europe, South America, and South Africa are other areas looking for suitable teaching materials. We have written our textbook and supporting tools to enable instructors to develop engineers and other professionals who have the thinking skills for competing successfully in the global marketplace of the twenty-first century.

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Monika Lumsdaine has a background in mathematics and solar home design. She is certified in the administration and interpretation of the Herrmann Brain Dominance Instrument (HBDI) and has conducted longitudinal research into the thinking preferences of engineering students. As a visiting scientist, she has team-taught creative problem solving courses at the University of Toledo and Michigan Tech. Her current work as management consultant for corporate behavior is in team building in industry, hospitals, and universities. With her husband, she teaches creative problem solving workshops in the U.S. and abroad.