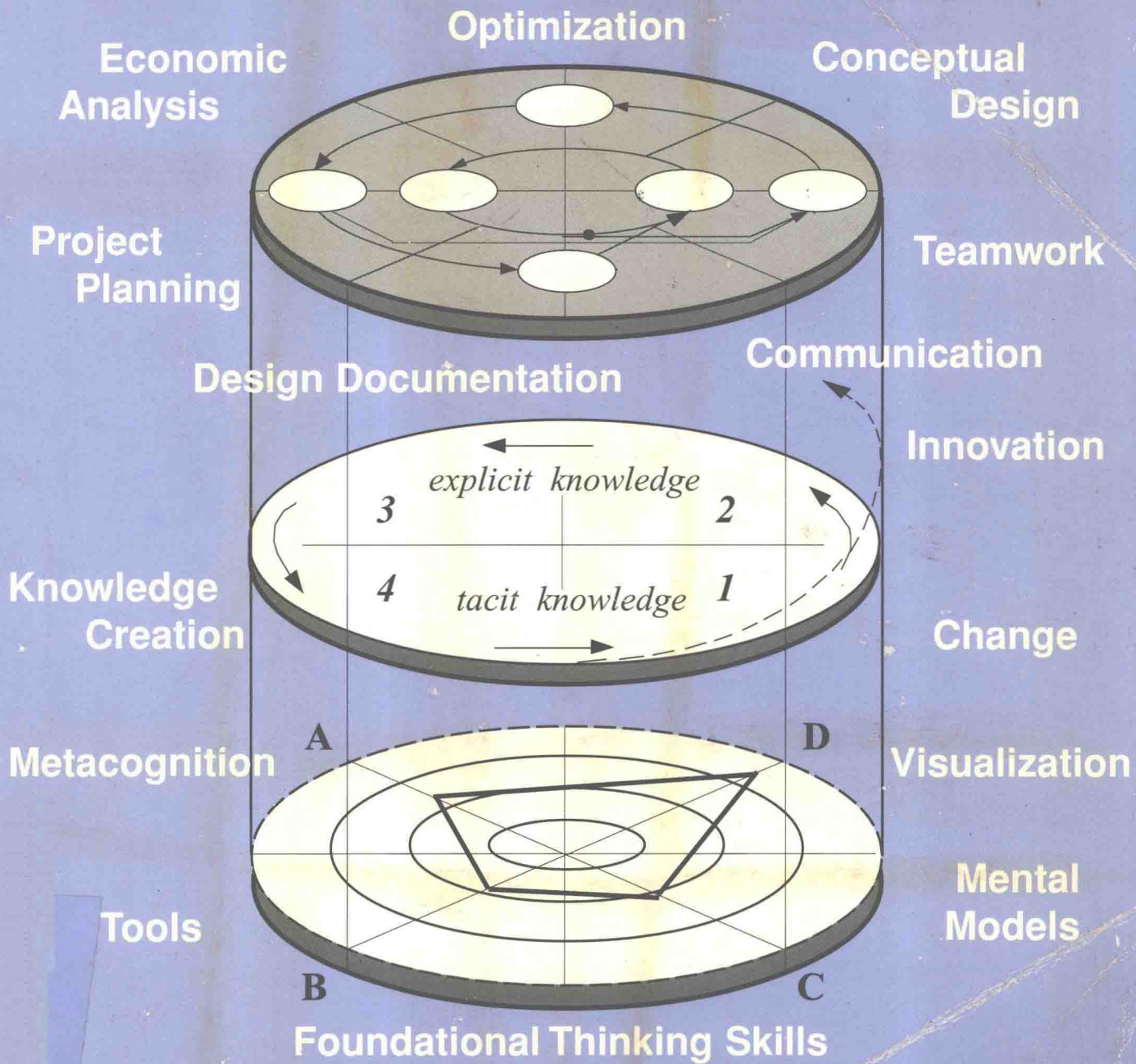
Creative Problem Solving and Engineering Design



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CREATIVE PROBLEM SOLVING AND ENGINEERING DESIGN

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To our children Andrew, Anne, Alfred, and Arnold,
their spouses Wendy, Jim, Becky, and Sarah,
and our grandchildren Benjamin, Emily, David, Bethany, and Stephen.
E.L. and M.L.

To my wife Joy and our children Greg and Michelle, their spouses Ellen and Joe,
and our grandchildren Emily, Amanda, and Colby.
J.W.S.

About the Authors

Edward Lumsdaine is currently Professor of Mechanical Engineering at Michigan Technological University and Management Consultant at Ford Motor Company. He previously worked as research engineer at Boeing and held faculty positions at South Dakota State University, the University of Tennessee, and New Mexico State University. He directed the New Mexico Solar Energy Institute and the Energy, Environment and Resources Center at the University of Tennessee, and he was a visiting professor in Egypt, Qatar, and Taiwan. His research projects have spanned many fields from heat transfer, fluid mechanics, turbomachinery, aeroacoustics, solar energy, and robust design (Taguchi methods) to teaching with microcomputers. For thirteen years, he was Dean of Engineering—at the University of Toledo, the University of Michigan-Dearborn, and Michigan Tech. He has pioneered the contextual approach to teaching engineering courses, and for many years he has taught math review using integrated software to engineers in industry. He served as on-site reviewer for the National Science Foundation's engineering education coalition program. Dr. Lumsdaine is a fellow of the American Society of Mechanical Engineers and an associate fellow of the American Institute for Aeronautics and Astronautics. He received the 1994 Chester F. Carlson Award from the American Society for Engineering Education for "designing and implementing significant innovation in a changing technological environment." He has been instrumental in developing the high-tech C3P education and training program at Ford Motor Company, and his current focus is on how innovation can be enhanced in the technical workplace. Ed grew up in Shanghai and made his way to the United States by working for nearly two years on a Danish freighter. He joined the U.S. Air Force and four years later entered junior college in California where he met Monika.

Monika Lumsdaine came to the U.S. from Switzerland in 1958, received a B.S. degree in mathematics with highest honors from New Mexico State University, and became involved in solar energy work through her husband. She founded her own consulting company, and she designed the visitors/operations center of the photovoltaic facility in Lovington, New Mexico, as well as a number of private residences. Her second design won a national award from DOE/HUD. She has extensive technical writing experience in energy conservation, passive solar design, product quality, and engineering. Edward and Monika Lumsdaine developed the math/science Saturday academy for secondary school students in Ohio, and they team-teach creative problem-solving workshops in the U.S. and abroad. Monika 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 (for students, faculty, staff, engineers, managers, and physicians). Through Monika's HBDI consulting project at the University of North Carolina at Charlotte, the Lumsdaines became acquainted with the work of Bill Shelnutt and realized he would make an ideal co-author for strengthening the engineering design focus in their creative problem solving book. Monika is the main author of the teaching manual that accompanies Parts 1 and 2 this book. It will be available for downloading from the web—the new paradigm of publishing answer books.

James William (Bill) Shelnutt, P.E. is currently Professor of Engineering Technology at the William States Lee College of Engineering, University of North Carolina at Charlotte. In early 1998 he was appointed to serve in the office of the Provost at UNC Charlotte as a faculty associate for teaching/learning/technology, distance education, and program assessment. He earned a B.S. in mechanical engineering from General Motors Institute and an M.S. in systems engineering from the Air Force Institute of Technology. Professor Shelnutt has taught capstone design courses for over 20 years. While at the University of Cincinnati's OMI College of Applied Science, he worked with a faculty team to develop the senior design project course sequence, and he served as Head of the Department of Mechanical Engineering Technology. At UNC Charlotte, he developed the senior design project courses for Mechanical and Manufacturing Engineering Technology, and he served as Chair of the Department of Engineering Technology. He also developed courses and workshops in statistical process control, total quality systems, and designed experimentation. Most recently, he led a faculty team to develop a successful new sequence of introductory courses stressing conceptual design and team skills for all students entering the College of Engineering, and he headed a team of faculty from five universities in developing and presenting a multimedia course in total quality systems. He is certified in the administration and interpretation of the HBDI and certified to facilitate training in the Seven Habits of Highly Effective People for UNC Charlotte personnel. He is also experienced in creative problem solving and team building at universities and in industry. He and his wife Joy live in the beautiful Blue Ridge foothills.

PREFACE

The purpose of this book is to enable engineers and technologists to be more innovative in conceptual design. The integration of creative problem solving with engineering design incorporates a unique double focus: (1) Visualization, cognitive models, teamwork, communications and creative problem solving respond to the needs of industry for employees who have these foundational thinking skills 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). (2) Application to the twelve steps to quality by design, including "how to" guidelines, planning and economic analysis tools (attached on a DC-ROM) and a library of design documentation formats which enable its users to concentrate on opimizing their design projects and solutions and prevent dysfunctional teams.

The book can be used for three different types of courses depending on the degree of emphasis plased on process (creative problem solving) or product (a rigorous yet innovative design project outcome):

- First-year courses, such as Introduction to the Engineering Profession, CAD, and Conceptual Design—to begin developing the skills that will form the foundation for everything that follows.
- Creative problem solving courses (including design competitions or other multidisciplinary student team projects) for sophomore and junior level students—with topics delivered in a just-in-time format.
- Capstone courses, such as Senior Design Projects.

The book is also a useful resource for engineers and design professionals just starting to work in environments where teamwork is emphasized or where rapid technological change is occurring. Key topics can be taught in on-site seminars or workshops.

To instructors and students alike, the book is challenging, user-friendly, and very practical. At each step, we tried to answer the question of what tools and techniques we could provide to make learning and engineering design easier, more effective, and of higher quality. Although the three parts can be studied sequentially in the conventional manner, the parallel tracks of Part 2 (creative problem solving) and Part 3 (conceptual engineering design) shown in Figure 1.2 on page 8 offer unique flexibility for addressing a variety of needs and learner levels. Many learning activities reinforce theoretical knowledge with immediate application and practice of a broad range of thinking skills.

This book is an ideal companion to the software manuals that teach students a particular design tool. It supplements the more traditional design methodologies with a global, future-oriented outlook and an emphasis on thinking. Here is a brief summary of the chapter content:

Part 1—Fundamental Skills and Mental Models. Chapter 1 provides the big picture—what thinking skills are needed for succeeding in the rapidly changing, global world of the twenty-first century? It also gives hints for effective learning. Chapter 2 enhances memory, visualization, and sketching. Chapter 3 presents three interconnected mental models: Herrmann brain dominance, knowledge creation, and creative problem solving—these frameworks are powerful tools for optimizing learning, teamwork, communication, and innovation. Chapter 4 discusses team development and how to form and manage whole-brain project teams, and Chapter 5 focuses on verbal communication, negotiating a win-win outcome, and technical design communication. Chapter 6 recapitulates Part 1 by showing how to overcome mental blocks to creative thinking.

Part 2—The Creative Problem Solving Process. Three knowledge creation cycles are represented by the creative problem solving process. Chapter 7 teaches how to explore the context and analyze the causes as part of defining the real problem (first cycle). In Chapter 8, students learn the principles of brainstorming, in Chapter 9 the process of idea synthesis, and in Chapter 10 idea judgment. Chapter 11 discusses the Pugh method of creative design concept evaluation and optimization (completion of second cycle). Chapter 12 constitutes a third cycle, as ideas are "sold" and implemented and as the process is monitored and evaluated. Each chapter includes directions for individual and team exercises to practice the creative problem solving process.

Part 3—Applications to Engineering Design. Here, the techniques of creative problem solving are applied to engineering design processes. This part can also serve as a curriculum guide and source of assignments for various types of design courses. Chapter 13 defines "engineering design" as communication in a way that leads to implications for all stages and aspects of the design process: customers, products, processes, systems, ethics, and stewardship. Chapter 14 gives the twelve steps to quality by design, including the concept, parameter, and tolerance design stages; identification of constraints, quantitative design objectives, planning, economic analysis, optimization, evaluation, and presentations.

Chapter 15 presents templates based on Microsoft Project 98 to help designers and students plan their team design projects and stay on track. Chapter 16 introduces economic decision making principles that need to be applied during the design process; their application is made easy through a new program, COMPARE, based on Microsoft Excel. Chapter 17 is a compilation of the entire set of design documentation formats needed in the twelve steps of quality by design. In Chapter 18 students will learn how to spot creativity in organizations and how to function in a creative way (whether or not the workplace environment is supportive of innovation). A technical Appendix provides an awareness of analysis and quality tools used in industry.

Our basic belief is that students can be taught to think more creatively when using the creative problem-solving framework with the design constraints in the optimal sequence of divergent and convergent thinking. In a recent seminar in Singapore, one student asked, "What if brainstorming results in something that is against government policy—what would you do?" Creative problem solving requires that we apply good judgment consistent with the values of the group and understanding the benefits and consequences of the decisions that are being made. Students also learn negotiation skills that can help in getting ideas and continuous improvement accepted. Weak or wrong solutions can be prevented when none of the steps in creative problem solving are omitted or interchanged in the design process.

The grander vision for the benefits of this book (which go beyond engineering design) can be summarized in the words of Paul MacCready, the inventor of such low-energy aircraft as the Gossamer Condor and the Solar Challenger: "No single technological advance will be the key to a safe and comfortable long-term future for civilization. Rather, the key, if any exists, will lie in getting large numbers of human minds to cooperate creatively and from a broad, open-minded perspective to cope with the new challenges." We trust that this book and what it teaches will become a valuable resource for students as they progress through the engineering or technology curriculum and then move on to the industrial workplace, to positions of organizational management and leadership, or to being entrepreneurs in their own businesses.

ACKNOWLEDGMENT

We are deeply indebted to so many people—known and unknown—for what we have learned about creative thinking and for many valuable and intriguing ideas that have found their way into the different versions of our books focused on creative problem solving.

We began with *Creative Problem Solving/Brainstorming*—a grey workshop manual for engineers and managers in industry. Next came training manuals for workshop instructors, teachers, managers, and engineers. The fifth version was a manual for an engineering orientation course at the University of Toledo, followed by a manual for Dana Corporation managers, engineers, and trainers. It underwent a major revision to emerge as the first edition (white cover, 1990) of our textbook published in the College Custom Series by McGraw-Hill: *Creative Problem Solving: An Introductory Course for Engineering Students.* A major revision, *Creative Problem Solving: Thinking Skills for a Changing World,* was published by McGraw-Hill in its College Custom Series (black cover, 1993) and incorporated our effort to reach a broader audence. With thorough editing and updating, this became the green-cover edition published by McGraw-Hill in 1995 under the same title.

With the changes being mandated in engineering education through ABET, we saw the need for a new edition that would include a strong emphasis on engineering design, teamwork, communication, and innovation. Thus Bill Shelnutt joined us as co-author—his extensive experience with teaching engineering design and with quality teams in industry has been extremely valuable in making the book more practical for engineering and technology students. He brought the twelve steps to quality by design to the book, including the design documentation and the planning and economic analysis tools on the attached CD-ROM.

We are grateful to many students, workshop participants, readers, reviewers, and faculty members who have used our books—their feedback has enabled us to continuously improve our material. Also, many ideas and interesting quotes from other authors have found their way into our lectures. When we were ready to publish, we wanted to give credit to all these contributors. Alas, we were unable to identify the source of many of these items. For this we apologize. Where possible, we have added brief comments to the references listed at the end of each chapter, identifying key concepts, ideas, and special vocabulary that we have incorporated into our text. Ken Hardy, an elementary teacher in

Toledo with a sense of humor, sketched many of the original illustrations and deserves a special thank-you. We are still using his line drawings of the creative problem solving mindsets in the overheads (Teaching Manual). The mindset drawings for the 1995 edition were made by Geoffrey Ahlers, an artist from Copper City, Michigan. Don Kilpela, Jr., of Copper Harbor, Michigan—yes, he is the captain of the *Isle Royale Queen III*—developed and drew the cartoons for the present edition. It was fun to observe his creative mind at work as we brainstormed ideas, and his contributions (the drawings as well as the messages) are very much appreciated.

The partnership with Bill Shelnutt added a new dimension to our teamwork and synergy, aided by phone, fax, a face-to-face meeting and work session for the final "design review" and frequent file exchanges by e-mail for feedback, discussion, and integration during the writing and revision process for continuous improvement. We had to employ much creative thinking to cope with balky or incompatible equipment and many detours in our schedules along the way.

Three individuals stand out in our own journey to increased creativity. At the stimulating Creativity Institute at the University of Wisconsin in Whitewater in the summer of 1987, Roger Von Oech really did give us "a whack on the side of the head." Paul MacCready's designs of low-energy vehicles are wonderful examples of his creative spirit and concern for a sustainable future. Ned Herrmann, the creator of brain dominance technology, is a tremendous inspiration to us for his enthusiasm and work in all aspects of creativity and whole-brain thinking. We want to thank him for unstintingly sharing his wisdom and materials with us.

We appreciate the people at McGraw-Hill who kept us organized and watched over the details, particularly Margaret Hollander, B.J. Clark, Margery Luehrs, and Ann Craig on the earlier editions, and Shirley Grall and Pat Dausener this time around.

Above all, the more we learn about thinking, design, and innovation, the more we stand in awe before the Mind of God, the Great Designer and Source of all Creativity.

April 1999 *Edward and Monika Lumsdaine*

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Note:
Resources for further learning (including references, exercises, and a review summary with key concepts and action checklist) are given at the end of Chapters 1 through 13.

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