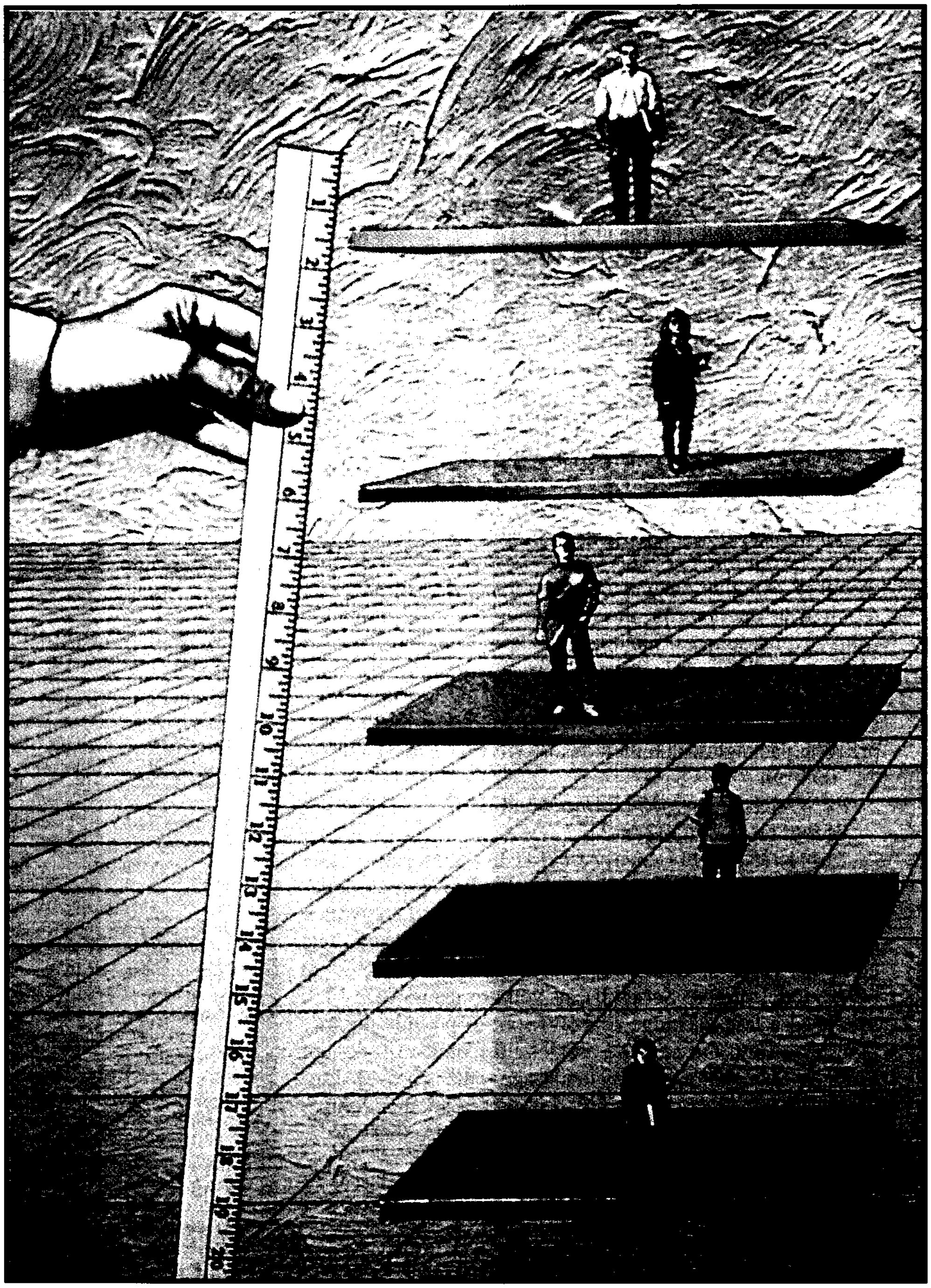
Team thinking that measures up to the task at hand.



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Creative problem solving

Spending more time in quadrant C will help your career

Problem solving, as commonly taught in schools, is an analytical or procedural approach. This approach almost exclusively employs left-brain thinking modes, is competitive, and relies on individual effort. However, *creative* problem solving is a framework that encourages whole-brain, iterative thinking in the most effective sequence; it is cooperative in nature and is most productive when done as a team effort.

The process and mindsets

Problem definition: Detective and Explorer

Idea generation (many ideas): Artist

Idea synthesis (better ideas): Engineer

Idea evaluation (best idea): Judge

Solution implementation: Producer

Fig. 1 is a graphic which illustrates the cyclic, iterative nature of the creative problem solving process and associated mindsets. Each mindset incorporates distinct thinking skills defined by the four-quadrant brain model of thinking modes or "ways of knowing" developed by Ned Herrmann, the father of brain dominance technology.

Ned Herrmann worked for many years at General Electric, first as a physicist, then in the area of human resource development. He became very interested in the relationship of creativity to the brain and over two decades developed and validated a model of brain dominance. Although based on the physical brain, it is now a very useful metaphorical model that can give insight into how different people think and communicate.

Each person's thinking profile is developed from responses to a 120-question survey form, the Herrmann Brain Dominance Instrument (HBDI) which was developed by Ned Herrmann. The resulting profile denotes a coalition of four distinct modes of thinking and processing information. Fig. 2 is a schematic of the Herrmann model of thinking preferences.

In the Herrmann model, the four quadrants of the brain are labeled A, B, C, D, counterclockwise beginning with the left cerebral quadrant. The thinking modes clustered within each quadrant have similarities; the modes in different quadrants identify distinctly different characteristics or ways of thinking. Each mode has value and is suited for particular tasks.

Quadrant A (the upper left cerebral quadrant) is *analytical*, rational, mathematical, judgmental thinking concerned with hardware, data analysis, financial budgets, and calculations.

Quadrant B (the lower limbic left quadrant) is *sequential*, controlled, routine, persistent thinking concerned with administration, safekeeping, maintaining the status quo, detail, tactical planning, and organization.

Quadrant C (the lower limbic right quadrant) is *interpersonal*, empathetic, people-intuitive, symbolic, value-based thinking concerned with communications, body sensations, music, nurturing, teaching, and training.

Quadrant D (the upper right cerebral quadrant) is *imaginative*, spacial, metaphorical, flexible, idea-intuitive, playful, creative thinking concerned with possibilities, dreams, visions, synthesis, strategic planning, change, innovation, and entrepreneurship.

Each quadrant has its own vocabulary and way of solving problems. Often, people with similar thinking preferences form tribes that tend to exclude those who are "different." Our thinking preferences determine how well we communicate with others; when we understand the four-quadrant model and work in whole-brain teams, we learn to understand people who have thinking preferences that differ from our own.

Ned Herrmann, from his extensive work with industry, found that the thinking profile needed to succeed in the 1960s was a profile that had its strongest preference in short-range, conventional wisdom thinking (quadrant B). The 1970s called for dominance in quadrant A thinking, since the focus was on technical and financial concerns. The profile for the 1980s was more whole-brained, with almost equal preferences in quadrants A, B, and C, and a slightly stronger tilt toward quadrant D, since strategic thinking and hi-tech development was needed. For the 1990s and beyond,

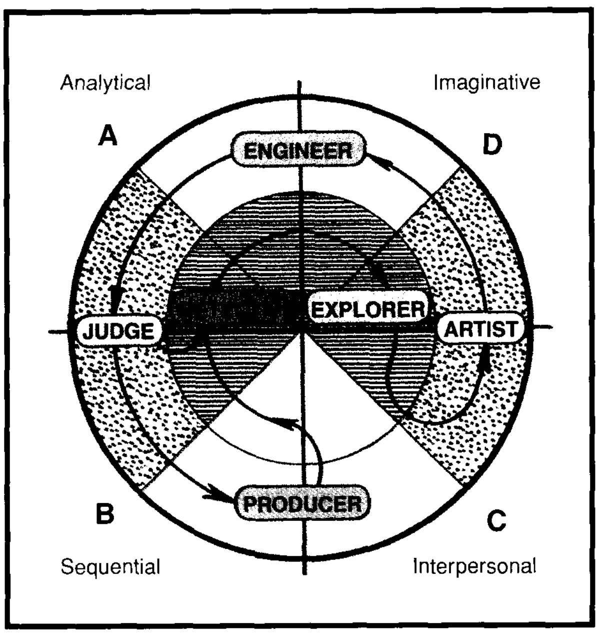

Fig. 1. Mindsets and thinking modes used in creative problem solving .

Edward Lumsdaine and Monika Lumsdaine

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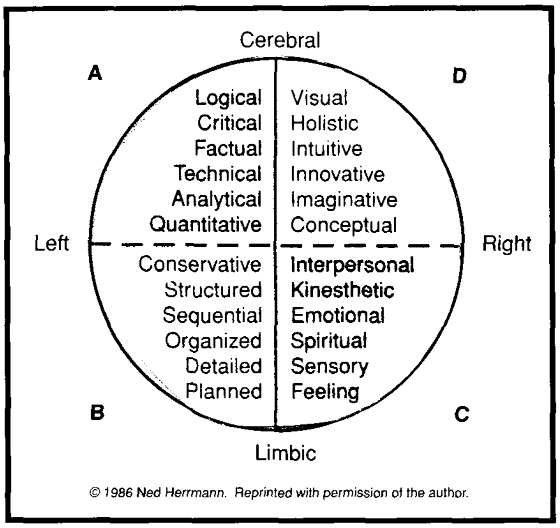

Fig. 2. The Herrmann 4-quadrant model of brain dominance.

quadrant D (as well as quadrant C) preferences have strengthened considerably with the new emphasis on global, long-range thinking. These profiles are shown in Fig. 3.

The process

We can use the HBDI to identify the thinking profiles of individuals. This allows us to form homogeneous and heterogeneous teams. The whole-brain team usually comes up with a more complete solution to an assignment; the members are able to identify the most appropriate problem solving approach for a particular problem since they have a broader arsenal of thinking strategies available to them.

Creative problem solving begins by asking: What is the *real* problem? We can picture a detective looking for clues and asking many questions to identify the causes of a problem. Engineers use analytical techniques such as Kepner-Tregoe, SPC, customer surveys, experiments, FMEA, FTA, and QFD to collect data to define the problem. For complete problem definition, we must then use the explorer's mindset: we must look for trends and the broader context of the problem. This requires right-brain thinking modes and involves looking to other disciplines, not just in one's field of expertise. The problem is then defined in terms of a positive goal to prepare the mind for the next step: brainstorming.

Idea generation is represented by the artist's mindset. The team is prepared for generating wild and crazy ideas with a creative thinking warm-up (if possible) and then employs a brainstorming technique appropriate to the size and composition of the team, the time constraints, the environment, and the problem being solved. A key rule to follow is to defer judgment; quantity counts, and "idea pinching" is allowed. All ideas that are generated are collected for further processing.

We have identified the next stage in creative problem solving with the engineer's mindset, because here we "engineer" ideas to make them better and more practical. Negative judgment continues to be deferred, but now we look for quality, and we use wild ideas as stepping stones to generate additional creative as well as practical ideas. Ideas are written on notecards and then sorted into categories. Categories are assigned to different teams—within each category, ideas are synthesized down to fewer, but better ideas. Finally, the teams try to forcefit or synthesize ideas between different categories.

The engineered ideas are now ready to be evaluated by the judge. Analytical and critical thinking skills are used to identify shortcomings. However, when flaws are found, the ideas are not discarded; instead, another round of creative thinking seeks to overcome the negative aspects of the ideas. The team employs the Pugh method of creative concept evaluation, an iterative matrix technique which leads the teams to develop a superior, compound solution based on brainstormed criteria derived from customer needs and team consensus. As a final step, the judging team then makes the decision to implement the optimal solution.

Solution implementation is a new problem that requires creative problem solving. We use the metaphor of the producer for this step. Structured thinking for planning the implementation and interpersonal thinking for working with people to accept change are now required. However, the producer team must repeat the entire creative problem solving process to obtain optimum results. Here again, established techniques for making work plans, monitoring plans, budgets, time schedules, risk analysis, and project evaluations can be employed, depending on the complexity of the implementation.

The course

We developed this method over a number of years. Our work started when we were asked by indus-

Table 1

Two ways of teaching heat transfer

Analytical approach	*Contextual approach*
• Students must know the fundamentals.	• Students must know the fundamentals.
• Minimal computer use.	• Extensive computer use.
• Artificial, neat problems.	• Real-life, "messy" problems.
• Problems are fully defined.	• Problems are open-ended.
• Students spend much time substituting in equations (plug-and-chug).	• Students spend much time in critical thinking and in asking "what if" questions.
• Only one "correct" solution expected.	• Multiple solutions/alternatives expected.
• Right-or-wrong answers.	• Contextual problem solving.
• Narrow focus on course or discipline.	• Multidisciplinary focus.
• Pure analysis—no design content.	• Application to design is central.
• Students work alone.	• Students work alone and in teams.
• Learning is teacher-centered.	• Learning is student-centered.
• Students fear risk; failure is punished. Learning from failure does not occur.	• Students examine causes of failure for continuous improvement.
• Quick idea judgment.	• Deferred idea judgment.
• Isolated, disconnected learning; no communications skills are taught.	• Students are required to make a verbal presentation and a written project report.
• Left-brain thinking only; the creative	•The creative problem solving approach and

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try to write a manual and teach workshops to engineering teams on how to think more creatively. It dawned on us that we were doing "remedial" work because something was missing in the way engineers were educated. Thus we developed a freshman course and textbook for engineering students.

Although creative problem solving forms the central part of our three-credit hour course, we have introduced related topics. We emphasize visualization and memory techniques to practice right-brain modes of processing information. We have incorporated a sketching lab as well as a computer lab using Mathematica™. We have a unit on how to overcome mental blocks to creative thinking. And we assess student thinking preferences with the Herrmann Brain Dominance Instrument (HBDI). The creative problem solving process is applied to a class exercise problem—a design project. The students are required to do a customer survey and Pareto analysis of the collected data. They must also do a literature search and a patent search.

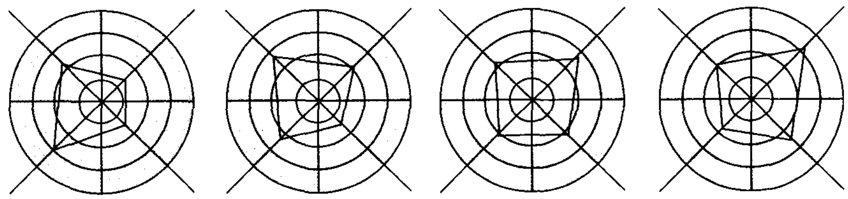

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Fig. 3. Paradigm shift in thinking preferences needed for success.

Just-in-time teaching about environmental and social considerations is provided depending on the particular design project. Ethics is discussed as related to the judge's mindset. Each team of five students is made up of different thinkers based on the results of the HBDI. We have found that whole-brain teams usually come up with superior solutions once the members learn how to work together. Communication skills are emphasized. Students learn to communicate with people that have different thinking preferences. They have to write a creative "thinking" report and are required to give a 30-second individual "speech" on the topic of their report.

For the midterm review, the students have a choice of completing an individual essay on five creative questions or doing a small team design project. The final exam is a team presentation on the results of the design project. Students also have to do a careful class evalua-

What kind of thinkers does industry want

The founder of IBM, Thomas Watson, made the word "think" his company's slogan. The word was plastered everywhere and employees were expected to at least act like they were thinking. And it apparently worked. IBM became a leader in the computer—notwithstanding its recent slowdown—by thinking up ways to stay on top.

So how does industry want you to think? What types of engineers are they recruiting? In 1992, Motorola listed these items as highly desirable in a quality briefing:

- Knowing how to learn,
- Listening and speaking well,
- Creative thinking and problem solving,
- Interpersonal relations and teaming,
- Self-esteem and motivation,
- Organizational effectiveness and leadership.

In a speech (at the 1994 Regional Meeting of the American Society of Engineering Education), Dr. Arlington W. Carter, Jr., Vice President of Continuous Quality Improvement at Boeing, mentioned that his company was looking for engineers who can work in teams, who can think creatively, who have a global view, who understand management and leadership, and who have the ability to cope with change. Dr. Mark A. Stumpf, Director of Corporate Plant Engineering Operations for Abbott Laboratories, emphasized that his company is looking for teamwork skills, leadership, creativity, and experience with diversity.

These companies take it for granted that graduates will have good analytical problem solving skills and solid knowledge of engineering fundamentals. They are looking for "value added." In other words, engineers for the 21st century have to be innovators capable of creating new products and new processes that generate jobs.

Dr. William M. Spurgeon, who has years of experience as vice president at Bendix, with NSF in Washington, and most recently as Director of Manufacturing Systems Engineering at the University of Michigan-Dearborn, reasons that innovation takes too long, costs too much, and often does not succeed in the marketplace because most universities are not preparing engineers adequately. He has developed an interesting function tree (to borrow a term from value engineering) for different types of engineering graduates.

Level 1: Degreed engineers are either *assistants* who are good at "plug and chug" problem solving or *creators* who produce most of the worthwhile ideas.

Level 2: Creators are either *problem solvers* who must be shown the significant problems or *initiators* who can find and identify the worthwhile problems.

Level 3: The initiators are either the *discoverers* who try to understand phenomena (the fundamental, curious researchers) or the *inventors and entrepreneurs* who try to utilize phenomena to some advantage. It is these entrepreneurs who are job generators.

One charge against our colleges of engineering is that they turn out far too few creators-initiators-inventors: the people who can operate the innovation process and thus generate jobs. Also, our graduates can no longer count on being hired by a large corporation; many need to have the broad skills useful to smaller companies or the skills required to start their own companies and make them succeed. In addition to engineering knowledge, they need political, legal, and financial know-how. — *EL & ML*

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Glossary

Kepner-Tregoe is an analytical method which employs long lists of questions to investigate a problem. The problem is defined as the extent of change from a former satisfactory state to the present unsatisfactory state. Finding the causes of the deviation should help solve the problem. This requires specific, quantitative data about the entire problem area.

SPC or Statistical Process Control is a collection of seven tools that use statistical data and comparisons to monitor processes. The goal is to keep variations and the resulting decrease in quality to a minimum. The tools of SPC are used to make graphs of the data; when these results are analyzed, the causes of problems can be identified. The seven tools are: checksheets, histograms, cause-and-effect (fishbone) diagrams, Pareto diagrams, scatter diagrams, control charts, and whatever additional documentation is needed to prevent problems.

FMEA or Failure Mode and Effects Analysis is used, for example by the Ford Motor Company, to explore *all possible failure modes* for a product or a process. Engineers look at the probability of a failure as well as the effect of the failure (and how easy or difficult it is to detect) in order to be able to prevent defects and develop test programs.

FTA or Fault Tree Analysis focuses on identifying a system's parts and events that could lead to or have led to *a single, particular failure*. The method graphically represents Boolean logic and directs problem-solving activities toward eliminating the failure from occurring by controlling all factors that could possibly contribute to the failure.

QFD or Quality Function Deployment is a very structured procedure invented in Japan and in recent years adopted by many organizations in the U.S. It employs benchmarking and the "voice of the customer" in a series of evaluation matrices, with the purpose of improving the quality of components of a product (or service) above the level of the best competing product, for those items most critical to customer satisfaction.

The Pugh Method of Creative Design Concept Evaluation is a technique where a team employs creative thinking to overcome the negative features and shortcomings of proposed designs. The ideas and concepts are placed together on a matrix and evaluated against a list of criteria. Through repeated cycles of discussion and comparing the improving designs against the top concept of the preceding round, the team converges on an optimum, synthesized design concept (or idea), where all flaws have been eliminated. True consensus and understanding develops on why this synthesized concept is best and the team members want to see it succeed.

Pareto Analysis employs a specialized bar graph to identify and separate the vital, most important causes of trouble from the more trivial items. Its first use was in economics. It is based on the 20/80 principle: by concentrating resources on the top 20 percent of the causes, 80 percent of the problems can be cured. It is useful for assigning priorities for continuous improvement efforts

tion. Imagine students choosing the final exam as the best part of the course—this is what has happened! Or students saying that they would have liked to have had more homework. The grading philosophy is "zero defect" or "hitting the target." Since there are alternate ways of achieving the goal, the focus is no longer on grades (and the resultant stress) but on individual and group excellence and learning. Students thrive on the interactive, hands-on, team-centered environment of this course.

From faculty's viewpoint

As engineering faculty, we can use the creative problem solving process together with the Pugh method to change the courses we teach so they fall more in line with industry requirements. The resulting contextual problem solving goes beyond engineering analysis and considers such aspects as the people/society interface, the environment, values/ethics, long-term effects, resource management, and costs (production costs as well as the cost to society of poor quality). Table 1 shows a comparison of analytical and contextual problem solving for a heat transfer course. This course was taught to juniors in electrical engineering.

The results have been surprising: the students learn much more; they can apply their skills in many new situations. They learn flexibility, leadership, and critical thinking. Even though the exams are longer and much more difficult, the class grade is now B-centered. In the past, as much as a third of the class dropped out or failed (and student performance centered on a grade of C)—now only a rare student drops out, and none have failed so far. Students have selected some very interesting design projects. Two students even received job offers because of their contact with industry as part of their project investigation.

How was it possible to incorporate these new activities into a course that already had a very tight syllabus? This is a legitimate question—we all know that the engineering curriculum is already overburdened. One thing is certain—without making some radical changes, we cannot add new materials, no matter how desirable they might be.

First of all, making extensive use of computers for problem solving and optimization (and report writing) saves time, and students are able to do more realistic, more complicated problems. But computers alone do not solve the problem: we had to sit down and actually look at each item we were teaching to decide its relevance. Is this topic useful? Is it teachable? Is it a duplication—is it covered in a preceding course, or will it be covered in a follow-on course? Does it fit into the context? Does it meet a need—in industry, in subsequent courses, in design? Is it integrated with other courses? We used the Pugh method for this evaluation. As a result, we were able to eliminate elegant topics dear to our hearts that took weeks to teach, yet were of no practical use to students today.

Like teacher, like student

Thinking preferences are strong filters in the learning process, especially if the instructor's preferences are "foreign" to the student's preferred way of thinking. Engineering faculty on the average have a distinct profile, with a strong preference in analytical thinking, lesser preferences in quadrant B and

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quadrant D thinking, and least preference in quadrant C thinking—their profile strongly resembles the 1970s profile identified by Ned Herrmann.

From 1990 to 1994, we collected HBDI data for freshmen and senior engineering students at the University of Toledo. We have found that the average profile for seniors closely resembles that of the faculty, except that students have somewhat higher scores in quadrant B, the "plug and chug" mode of thinking. Are we educating excellent engineers for the 1970s?

Our longitudinal research project with the HBDI shows that many students become more left-brain dominant as they go through the engineering curriculum, since the curriculum itself is extremely skewed toward quadrant A thinking. Students who have the right-brain-dominant "1990s profile" have had retention rates at least three to four times worse than the more traditional students. We have been losing the talented, creative students needed by industry!

When we analyzed the profiles of 1994 seniors who had taken the HBDI survey as freshmen, we discovered that 60 percent of these students have become more left-brained, with some making a complete switch from right to left. We found that 20 percent of the students developed their own ways of practicing right-brain thinking (such as seeking out group activities); these students remained "different" despite the curriculum pressures. The creative problem solving course gave them the affirmation that it was okay to be different.

Another twenty percent of the students made a noticeable shift to right-brain or whole-brain thinking—these were students who without exception received additional practice in creativity by being assistants in creative problem solving classes or helping in Saturday Academy. These students were the only group who increased in preference for quadrant C thinking.

We note with grave concern this considerable drop in quadrant C thinking by the left-brain students, even as industry demands engineers with interpersonal and leadership skills. Low quadrant C thinking also creates a classroom climate that is uncomfortable for some students. The only difference we have found between the average thinking preference profile for men and women students is in quadrant C. Here women, on the average, have a noticeably stronger preference. Based on early data from University of Toledo students, quadrant C thinking is a mode that many male students tend to avoid, particularly in computer science and mechanical engineering.

Conclusion and implications

We believe our results confirm that quadrant C and D activities must be part of the engineering curriculum so individuals can develop their potential in all four thinking quadrants. This also will reduce the probability that those with right-brain thinking preferences opt out of engineering. Creative problem solving can be used to strengthen the productivity, quality of teamwork, thinking and communication skills of students and faculty in all four quadrants.

Traditionally, engineering faculty expected their students to have thinking preferences much like their own. All others would be "weeded out" during the freshman or sophomore year, since creative thinking is often covertly or actively discouraged.

Today, we are seeing incoming freshmen classes with roughly forty percent of the students right-brain dominant. Society cannot afford to lose the valuable thinking preferences of these individuals— because these are our future innovators and entrepreneurs.

Change is not easy; it requires patience, effort, and persistence. Whether you are still a student or already out in industry, seek out any and all opportunities for learning and practicing new thinking skills and teamwork. Thinking in a quadrant that is not a preferred mode requires more energy initially; thus we tend to avoid those modes. However, we can develop preferences if we make the effort, because the brain is "plastic" and undergoes changes in structure each time it is used. You can prepare yourself to take advantage of the opportunities ahead in the 21st century.

Read more about it

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• Edward Lumsdaine and Jennifer Voitle, "Contextual Problem Solving in Heat Transfer and Fluid Mechanics," *AIChE Symposium Series, Heat Transfer*—Atlanta 1993, Volume 89, pp. 540-548.

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About the authors

Dr. Edward Lumsdaine was a research engineer at Boeing, taught at South Dakota State University and the University of Tennessee, directed the New Mexico Solar Energy Institute and became Dean of Engineering at the University of Michigan-Dearborn, the University of Toledo, and most recently at Michigan Technological University. His research in heat transfer, fluid mechanics, aeroacoustics, solar energy, product quality, and innovative teaching is published in over 100 papers. He frequently conducts math review courses in industry with software he and his colleagues have developed. He received the 1994 Chester S. Carlson Award from the American Society for Engineering Education for designing and implementing significant innovation in a changing sociological and technological environment.

Monika Lumsdaine is a technical writer and award-winning passive solar home designer with a degree in math. She and her husband have developed and team-teach creative problem solving courses and workshops to engineering students and faculty, people in industry, as well as teachers, students, and parents. She is president of her own consulting firm, holds an appointment as visiting scholar at Michigan Tech, and is certified in the administration of the Herrmann Brain Dominance Instrument.

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