

PAPER #2

Session 2225

Introducing Creativity and Design into Traditional Engineering Analysis Courses

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The limitations of traditional teaching styles in engineering education are well-known^{1,2}. The authors have revitalized four traditional engineering analysis courses—Heat Transfer I and II, Fluid Mechanics and Introduction to Computing—in answer to the paradigm question³: "What can we do that would fundamentally improve the way our students learn, to prepare them to succeed in the high-tech, global environment of the 21st century?" Our response was to implement the contextual problem solving approach, where creative thinking and design are central. Curriculum reform was motivated by the statement, *"Our mission is to prepare our students to be world-class engineers, capable of coping with change and the challenges of the global marketplace in a multicultural society. Teamwork, synthesis of application and theory, design, communications, learning how to learn, and use of computers are vital components of the renaissance engineer."* Fundamental to our philosophy is that we teach "why" as well as "how" and address all student learning styles, not just the thinking modes preferred by the faculty.

Problem Definition

Since the Sputnik era, engineering educators have turned their focus from a hands-on, application-oriented curriculum to one which is more theory and science-based. This has resulted in large numbers of engineering graduates who, in general, understand the science of engineering but not the art and design part of engineering. Many faculty teach the way they have been taught, and the emphasis on elegant formulas and theory (however unproductive of the real world) is passed on to their students. Thus the cycle begins anew. Industry has complained about this problem, and it is not uncommon for this customer sector to give feedback that our graduates can analyze and plug-and-chug, but cannot think critically, work in a team, communicate, solve real-world problems, or cope with change. Additionally, graduates have difficulty functioning in a multi-cultural, global marketplace, coming as they do from an overwhelmingly homogeneous domain where individual effort is glorified and rewarded and where teamwork in classes is regarded as "cheating."

Engineering courses (as well as the liberal arts core curriculum) are not integrated and are thus viewed as isolated entities. Students are then unable to put their knowledge into the proper context. For example, students often fail to make the connection between what is taught in thermodynamics and in heat transfer. They also have difficulty relating concepts learned in mathematics to their engineering courses. As an example, all of our students could perform the following operation in their calculus class:

$$\int \frac{1}{x} dx$$

When confronted with the same problem in thermodynamics, the majority of the students could not carry out

$$\int \frac{1}{v} dv$$

When questioned, they said that they were confused about the meaning of the term v ; had we written x instead, they could have solved the problem. They also complained that asking them to do such a problem was "unfair", and that we were "trying to trick" them. It seems that when mathematics is done outside of the math class, many students are surprised that "it still works," and they are confused when we work with actual properties (such as v for specific volume) rather than with abstract symbols. Another problem is that students often memorize results with no real comprehension of the meaning. Students may wonder, for example, *why* the pressure increases in subsonic gas flow through a diffuser. When they question this, more often than not, they are referred to the formulas or told that "this won't be on the exam, so don't worry about it." Thus the fault lies not with the students, but with our failure to help them to assimilate and integrate their knowledge into a contextual framework.

The problem is complex and does not have a quick fix. However, we have become increasingly aware of the need to

change our curricula, our teaching styles, and our evaluation methods. One of the ways that we are doing this is by changing our mindset: we now teach contextual problem solving. We feel that design and creative problem solving should be made part of each engineering course, beginning with the freshman year. Much too frequently, students are taught theory until a senior capstone design course. Co-op students, because they have meaningful work experience, do have a broader understanding and appreciation of the skills that are required by engineers. In the capstone or synthesis course, students finally get to apply their knowledge in a real-world project solving a realistic problem, but by this time, we may have lost some very talented students to other disciplines. Even in universities that teach a separate course in creative problem solving, efforts need to be made to integrate this material into the entire curriculum. Successful curriculum reform requires: a mission statement; change in the professors' mindset; identification of important topics and concepts from customer surveys and topic flow analysis, and integration across the curriculum. We have to begin teaching the students, not just the subject matter.

We have a growing consensus that curriculum reform is needed—but how to go about accomplishing this reform is another matter. We will describe the approach that we have initiated: (a) using a tool for assessing student and faculty thinking preferences, (b) its application to curriculum contents analysis, (c) the process of redesigning an engineering course with a concrete example, and (d) integrating teamwork into courses and how to evaluate creative teams. The effort described here did not happen in a vacuum—it followed from our involvement in teaching and implementing creative problem solving into the curriculum.^{4,5} What we are describing here is the next step—we now have experience in reforming three existing undergraduate courses: Heat Transfer I and II and Fluid Mechanics (in Mechanical Engineering), and we are currently revitalizing Introduction to Computing (in Computer Science and Engineering). Each course had specific goals, obstacles and problems to overcome, thus different strategies were used. The computing course was a prime candidate for reform—a university self-study over a period of several years indicated that this course was one of the most disliked by students and the least useful.

The Herrmann Brain Dominance Instrument (HBDI)

The HBDI is a self-assessment tool of an individual's brain dominance profile and thinking preference modes.⁶ At the University of Toledo, we are engaged in a longitudinal research project where we survey our engineering students as freshmen and again as seniors. We have also surveyed the faculty and the seniors in the pipeline. According to the Herrmann model, the brain can be visualized as a four-quadrant metaphorical model, where each quadrant is characterized by distinct ways of

thinking, knowing, and processing information. The four quadrants are summarized in Figure 1.

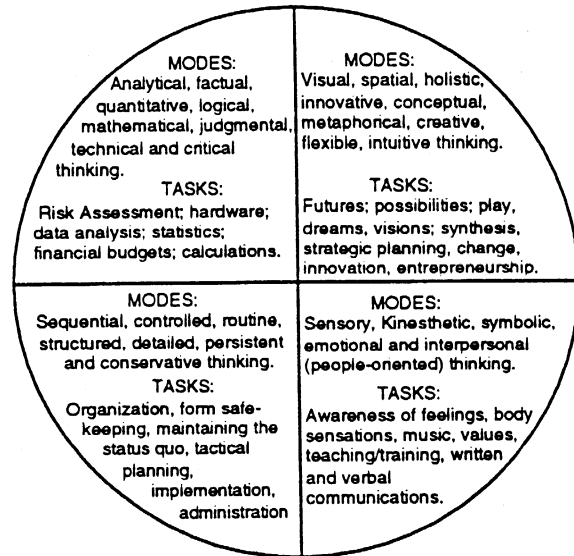


Figure 1 The Herrmann Brain Dominance Model.

Just as people may prefer the use of their left hand over the right, so they may prefer to use a particular side of the brain or a particular thinking mode. In general, we are not surprised at the HBDI data that we have collected so far which show that many of our engineering students and professors are predominantly left-brain thinkers, as depicted in the averaged profiles in Figure 2. Some freshmen classes are almost evenly balanced between students who prefer left-brain quadrant A and quadrant B thinking and those who prefer right-brain quadrant C and quadrant D thinking. We have found a correlation between high right-brain thinking preferences and low retention in engineering, even though these students get top grades in analytical courses. A dominant reason for their choosing other majors is the inhospitable learning climate in engineering which does not accommodate their thinking preferences, even though voices in industry are increasingly demanding engineers with precisely those thinking skills. By the time the students are seniors, their averaged profile closely matches the faculty's profile. This may in large part be due to the fact that right-brain thinkers are neither rewarded, encouraged, or comfortable in the traditional engineering curriculum—in essence, they are made to feel like "outsiders." Consequently, they either drop out or perhaps flunk out. It is also possible that they learn to conform to the left-brain pattern—this is one aspect that we will be able to assess next year, when the first class of freshmen tested with the HBDI .

characteristics to be graded includes the following items:

- Did the student participate to the maximum of his/her ability?
- Were good communications skills observed?
- How were conflicts resolved?
- Did the student exhibit a cooperative attitude?
- What was the level of support for the team's efforts?

In the heat transfer course, the team projects counted for 30 percent of the student grades. The students and their projects were evaluated by a team of instructors who had co-taught the course. The project evaluation was equally weighted between verbal presentation, technical content, and report writing (each counting 10 percent toward the final grade).

Recommendations

Traditional engineering analysis can be significantly improved by introducing creativity, design, the customer interface, and teamwork into these courses, the earlier the better. The curriculum should reflect the needs of all our customers, not just maintain the status quo. Many professors teach very well and are not rewarded, while others teach poorly and are neither reprimanded nor encouraged and shown how to improve. The success of curriculum reform should not depend on individual personalities or teaching styles. As teams, engineering departments should decide on common goals, including writing a mission statement, to optimize the customer's needs, faculty talents, and resources. For example, the QFD House of Quality⁸ is an effective tool for analyzing the curriculum. We have applied the Pugh method profitably to assess individual course content. Creative course evaluation, design, and implementation can turn unsatisfactory courses into stimulating learning experiences for students and faculty.

References

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- 5 Edward Lumsdaine, "Six-Year, Six-Topic Engineering Faculty Enhancement Program," *Proceedings, ASEE Annual Conference*, New Orleans, June 1991, Vol. 1, pp. 59-64.
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- 7 Edward Lumsdaine and Wen J. Wu, "Interactive Computer Software for Teaching Heat Transfer", Session 2225, ASEE Annual Conference, Urbana, Illinois, June 1993.
- 8 Edward Lumsdaine and Monika Lumsdaine, *Creative Problem Solving: Thinking Skills for a Changing World*, p. 189, McGraw-Hill, New York 1993 (College Custom Series).

mission statement. We then surveyed our customers (industry, students that had taken the courses, and other professors) to assist us in prioritizing pedagogical topics and to determine what tools and knowledge should be provided to our students. We used the Pugh method in our analysis, after brainstorming evaluation criteria for the topics. One of the most radical overhauls occurred in the computing class. Since its inception, the course has been devoted entirely to the study of computer programming. Despite the advances in modern computing and changes in customer needs, the sole language taught and used is FORTRAN 77 (without extensions) on the campus IBM mainframe. The course evaluation showed that the course was being taught in an environment totally divorced from engineering. Other factors contributing to the low course rating, which were identified by complaints from students and survey results, include: large class size (requiring that the class be taught in an auditorium); no required lab period; no capability for mainframe connection and online demonstration in the classroom; no design or creative aspects; routine, dry assignments such as grade average computation; mismatch of course prerequisite requirements and assignments; insufficient student help, and an interdisciplinary class in which students range from freshmen to doctoral students (whose majors vary from every engineering department except computer science to health and physical education). The student diversity makes it difficult to choose homework relevant to all students, unless this diversity is viewed as an asset and applied to teamwork (which we have begun doing). The combination of these factors was detrimental to student learning, resulting in frustration and dissatisfaction by students and instructors.

The course has been changed from one which consisted of approximately 20 percent quadrant A activities and 80 percent quadrant B focus to one which is more balanced at approximately 20 percent each for quadrants A and B and 30 percent each for quadrants C and D. Now, teamwork and design are emphasized, and "following the rules" in canned, routine programs is deemphasized. Four areas of computing are now addressed—programming, graphics, text editing and simulation—rather than the single area previously covered. Students still learn the fundamentals of programming and are still using the mainframe and FORTRAN 77 (since we were unable to get support to change these for budgetary and administrative reasons), but with the changed emphasis students are actively involved in the course, rather than passive recipients or spectators. FORTRAN is only taught for part of the course; now the students are introduced to the C language and SMP use and programming in *Mathematica*. All of the assignments are motivated by student experiments and questions. The design projects are related to engineering and involve all four quadrants of the brain. For example, one of the design projects requires students to design, simulate, build and optimize structures to withstand certain loading conditions. The students are also modeling diving boards, gathering

necessary data and performing tests at the University swimming pool. The students are very receptive to these projects and the presentations they are required to make. Field trips are also made (to areas using computers in design and simulation) to motivate the students and enhance learning.

In the heat transfer course, our emphasis on design and creativity means that the students are solving harder and more complex problems than before. They are required to use heat transfer computer software developed for the course and to do team design projects. The team project outcomes demonstrate that the students really understand the concepts involved, and this increased understanding has been reflected in a shift from a mean grade of C to the current median of B+.⁷ Similar results can be reported for the fluids course, where the average grade is now A-. Since incorporating teamwork throughout a course is a major paradigm shift for many faculty, we want to discuss how we encourage and evaluate teamwork.

Forming Creative Teams

Many students have no experience working in teams (except for lab groups) and careful consideration must be given to this. We have found that our students must usually be educated as to what makes a good team member. They may at first be uncomfortable with being evaluated as part of a team. Some of the characteristics required of the members of a creative team include: communication and listening skills; a willingness to learn from each other; sharing and building upon ideas, and asking questions; flexibility, humor and optimism; a willingness to contribute and help; self-discipline and self-confidence; a willingness to take risks; the ability to see the whole picture; humility, politeness and patience.⁸ In college courses, we have little influence in the selection of our students, but effective teams can be formed by taking each student's individual personality and talents into consideration. We use the Herrmann Brain Dominance Instrument as an aid in forming the student teams and find this very effective.

Evaluating Creative Teams

A significant problem encountered by both instructors and students is the evaluation of teams. Instructors may fear that some students will not carry their load and will receive an undeserved grade. Students may fear that they will be unfairly penalized for one uncooperative or noncontributing member, resulting in their doing an unfair share of the work or receiving a lower grade than they would have earned on their own. In order for creative team evaluation to work, the teams and instructors must agree on common objectives, goals and evaluation criteria. In a faculty workshop, our professors have been encouraged to evaluate each student's team skills by an observer (such as a class assistant), through self-evaluation (completing a checklist), and by anonymous feedback about each team member by others on the same team (in the form of constructive, positive comments). A list of student

will be retested as seniors. Yet the engineering profession needs right-brain thinking skills since approximately eighty percent of industrial problems require creative, flexible, and critical thinking as well as interpersonal skills.

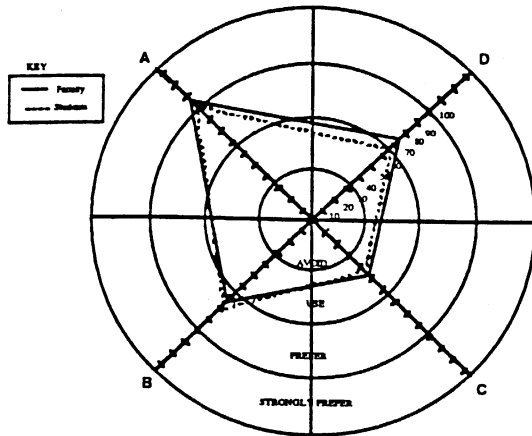


Figure 2 Comparison of Engineering Faculty and Undergraduate Seniors.

For some years, we have assumed that the seniors exhibited the typical faculty profile because of their direct interaction with the faculty in the teaching process, and because these might have been students who from the start had profiles that were compatible with those of their professors. However, we now are beginning to understand the influence of the curriculum with its almost exclusive concentration in only one or two thinking quadrants in shaping the senior student profile. Our results so far also indicate that the only difference between the average male and the average female profile is a stronger preference for interpersonal quadrant C thinking for females. Since this is the area of least preference for faculty and seniors, this has serious implications for the retention of female students in engineering.

Curriculum Evaluation

The engineering curriculum has not changed significantly in at least the past thirty years. Many students as well as professors, and certainly our industrial customers, have felt dissatisfied or uncomfortable with the curriculum. We have used the Herrmann Brain Dominance Instrument to analyze the Mechanical Engineering Curriculum at the University of Toledo. We used the 1991 curriculum which predates the revision of the engineering courses described here. The profile of the curriculum shows that it is extremely skewed toward left-brain thinking skills. The generic Ned Herrmann classification of this profile is 1-1-3-3 which means that quadrants A and B (analytical and sequential skills) are strongly preferred, while quadrants C and D (interpersonal and imagination skills) are avoided. For comparison, the averaged

faculty profile is a 1-1-2-1. This implies that creative design and communications are being avoided in the curriculum; even when nominally included in the syllabus, the associated topics are taught in an analytical manner. Since the averaged engineering faculty profile indicates some strength in the C and D quadrants, our interpretation is that the curriculum is being driven by the A and B dominant people. The B-dominant administrator wants to "maintain the status quo" while the A-dominant professor wants to collect and analyze data. Quadrant D people have many creative ideas, but these profiles are often accompanied by low preferences for quadrant B thinking, whose persistence is necessary to get ideas implemented. Change also requires consensus building and teamwork which again are not preferred preferences among engineering faculty. These thinking patterns may explain why we have seen little significant change in the curriculum despite customer complaints and much study. In the College of Engineering, our goal is to revitalize our curriculum according to the pattern of Dana University, as shown in Figure 3.

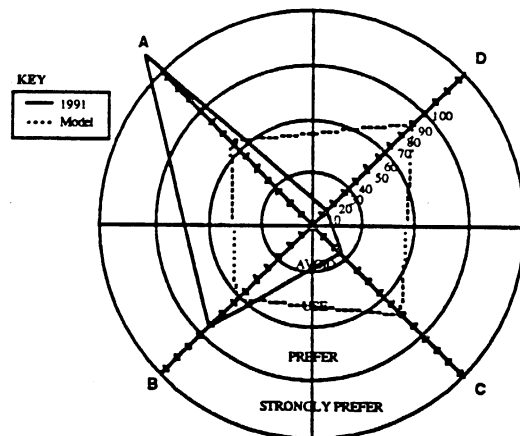


Figure 3 Comparison of the 1991 Mechanical Engineering Curriculum and the Curriculum Model (Dana University).

To achieve the model curriculum, we must introduce far more creativity, design, innovation and teamwork into our courses—having an introductory course in creativity and problem solving is simply not enough. Note that not all courses need reflect the whole-brain pattern, as a cluster of courses can be designed to fill complementary needs. In order for this reform to be successful, professors, students and administrators must begin to work together as teams.

Course Redesign: Example

We have targeted these undergraduate courses for reform: Heat Transfer I and II, Fluid Mechanics, and Introduction to Computing. We have analyzed the existing courses and redesigned them according to the principles of the contextual approach in teaching engineering courses¹ and our guiding