INTEGRATING CREATIVITY INTO THE MECHANICAL ENGINEERING CURRICULUM

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ABSTRACT

This paper discusses some of the ideas, philosophy and results from a series of faculty workshops organized by the authors to deal with issues of creativity in engineering education. Here we place particular emphasis on applying these principles in design courses. A premise of this paper is that good design education differs markedly from other types of engineering education. Moreover the socialization and the self-esteem aspect of the way design is offered in the university are important determinants of a student's subsequent professional career. This paper asserts that specific aspects of engineering education are ill-considered, even when they seem to produce good results. Specifically mentioned are: the use of design contests with winners and losers, design criticism of good and bad work, project groups versus individual design projects, reverse engineering versus direct engineering and the concept of what it means to "cheat" by copying, receiving help and not doing one's "own" work in the context of design. This paper suggests that certain norms facilitate innovative design education and that some of these may be in direct opposition to those currently applied in engineering classes. The authors feel that these questions are of special importance at this time because engineering education has become so strongly linked to the current rhetoric about competition in the market place.

1. INTRODUCTION

We agree with General Electric's long time management educator Ned Herrman [14, pp. 185–6]: "I resist defining creativity: Each person's experience of it is so unique and individual that no one can formulate a definition that fits everyone else. ... My own thinking is that creativity in its fullest sense involves both generating an idea and manifesting it—making something happen as a result." His view of creativity states the general attitude shaping the three American Society of Engineering Education (ASEE) Creativity Workshops described in this article.

The workshops came into being when Prof. Michael Rabins asked Bernard Roth to organize them at Stanford as part of ASEE's Faculty Development Program supported financially by the National Science Foundation. Rolf Faste took charge of them after the first was given in 1989. By now over 50 North American professors, mainly in mechanical engineering, have participated in one of the two-week workshops. A study of half the participants showed a statistically significant increase in a psychological measure of their personal creativity [Wilde]. This should arouse the curiosity of anyone concerned with the care and feeding of creativity in both students and faculty.

Consequently this article describes the workshop's philosophy, subject matter, techniques and background references from the literature of education and psychology. After exposition of the ideas and approaches shared by the authors, who were the three main workshop facilitators, the article details each individual's philosophy and technique. Finally speculations are offered on the psychodynamics of the workshops, with implications for design education.

Although the workshops dealt with many aspects of being an engineering educator, in this paper we will limit ourselves to several of the ideas that are particularly relevant to design education, and especially those aspects that differ from traditional notions of design education. The workshop allowed the participants to experience techniques and organizational arrangements which have been used by the authors and their colleagues at Stanford University's Design Division in order to create a cooperative learning environment. This paper has been written in order to introduce design-oriented educators to the types of issues we dealt with in the workshop and to share some of our results. This paper does not attempt to reproduce the specifics of the workshop since it is one of our basic premises that our workshop—like a design project or an exciting

voyage—has its main value in experiential learning and not in the telling of the tale.

II. INHERITED TECHNIQUES

Most of us learned to teach by copying the traditional methods which our teachers used. Although there are certainly personal differences and modifications do occur, very few people seem to approach teaching as a problem solving activity, which often requires new and creative ways of dealing with both short and long term goals. We feel very strongly that both professors and students need to be given "permission" to be themselves and not to attempt to mimic the "professional" behavior of their teachers—except of course where the mimicry leads to growth and expansion, not suppression of true inner self.

In this way the workshop attempts to identify for each participant vestiges from their past which are in fact dysfunctional in regard to good teaching. To understand this concept a little more fully, it is instructive to make a personal list of such techniques. The best source for items on the list are things we have done ourselves; secondary sources are things we remember from our own teachers and things we see being done by colleagues. From the perspective of design education, the personal list of the second author includes the following:

1. Material centered courses
2. Professor centered courses
3. Every student for her or himself—"ships passing in the night
4. Treating the material in isolation from other courses and life
5. Not getting your hands dirty
6. Using a project as an excuse to "teach" content
7. Student competitions

Our concerns with each of these are:

• 1 Material centered courses

Often instructors rush through "the" material in order to "complete" the course syllabus before the term ends. This satisfies a short term goal of "covering" the material at the expense of several much more important educational objectives—including understanding, learning, and retention. We think this is bad education, and feel we do a poor job when we fall into this trap. In education, as in travel and life, it is the quality and adventure of the journey that is meaningful, not the quantity of destinations quickly rushed through and soon forgotten.

• 2 Professor centered courses

The standard engineering course involves a passive student listening to a set of lectures (which may range from enlighteningly brilliant to stupefyingly boring). It is expected that the student take notes for later study in order to recall what was said and, hopefully, understand enough of the material to do the problem sets and pass the examinations. The lectures are augmented by individually done homework (including readings) and examinations from which the students are graded and sorted. The instructor takes responsibility for presenting the material and grading examinations; it is the students' responsibility to do the rest. This system works very efficiently in going through the motions of "teaching" university courses. From experience, we know that some students can do very well in such regimes, while other students get virtually nothing from such a regime. Ironically even those who do well often feel very insecure, as though they have fooled the system, and in fact some of them have. In our workshops we give the participants the experience of experimenting with different teaching and classroom styles.

• 3 Ships passing in the night

Most courses are organized so that the students work alone or with at most with one or two other people. In large schools with big classes students often do not even know most of the other people in the class. Even in small more intimate classes, they are expected to "do their own work." If they receive assistance it is often from the teaching assistant or instructor. Any assistance from peers is stigmatized as cheating or borders on cheating or copying. This promotes a mind set and attitude which is not conducive to teamwork and cooperation as part of a design team.

We believe this is bad pedagogy in all cases, and in design education it is completely wrong. It is extremely important for students to learn to assist each other collegially and to learn from their environment. This needs to be done in different ways. In the context of design education this can occur in project groups, in the guise of students acting as area experts or consultants, in group critiques, and in classroom discussions—both formal and informal.

• 4 Treating the material in isolation from other courses and life

There is a fairly large group of students who do well in their course work and yet do not have any sense of the relation of the material to actual real life engineering. This problem is as old as the study of engineering. For example, the following is typical of a lament that is often heard. "In the science of Mechanics it has especially happened that the mathematical study of the subject has been pursued with very little regard to its practical application. The consequence of this is, not only that our theoretical teaching is of little value in preparing for any part of the business of Engineering, but also, that it is of little value as intellectual discipline." [Whewell, 1841].

The problem of getting students to learn from their environment and to relate their formal training to the world around them is very critical in the area of design. We have found that the use of assignments to bring in manufactured objects and reverse engineer them, redesign them, and critically analyze them have been extremely effective. Here again, we need to break down the stigma about copying from others, and encourage students to copy every thing of use in the world around them. We find that cooperative peers and outside professionals can be of much greater assistance than even the most knowledgeable faculty member.

• 5 Not getting your hands dirty

Design is often taught as though the design process consists of a research phase that uncovers the facts, an ideation phase that develops the form of the design, and an analysis phase which gives all the important numbers.

Then, at the end, a prototype may be built. In contrast to this, we believe that one of the best ways to handle each stage of the design process is to plunge in and rapidly prototype rough solutions. The parts of these quick mock-ups that do not work will tell the designer where research and analysis time is best spent. Quick and dirty prototyping is in the best tradition of learning by doing—in this context it translates into designing by doing.

Rapid prototyping is used in almost all our design courses at Stanford. We encourage our students to use inexpensive easy to work materials, such as foamcore, and to quickly produce rough "crap-ups." In some courses we hold periodic "hardware bazaars," where rough prototypes are presented in the manner of a poster session. In the creativity workshops we include a prototyping experience, and also a visit to Silicon Valley's leading design firm where rapid rough prototyping has been used to develop hundreds of new products.

• 6 Using a project as an excuse to "teach" content

One of our premises is that good design education differs markedly from other types of engineering education. It is not simply another set of content with the word "design" appended to the title. We believe that any course without student projects is not a design course. That does not mean such a course is bad or should not be offered, or that it is not of value to design education, we just means it is not a design course. It certainly can be about design, but it is not a design course. So courses with titles such as "Basic Principles of Design Morphology," or "Failure Analysis in Design," or "Design of Thermal Systems," may or may not be actual design courses. In our view they are not design courses if their real aim is to teach the content of, respectively, design morphology, failure analysis, or thermal systems. They are real design courses if the objective is to give the students supervised design experiences in which they incidentally consider, respectively, the morphologies they followed, the possible failure modes of their designs, and the thermal aspects of their designs.

The distinction between the two different approaches is crucial. In the first case the content drives the design and in the second case the design drives the content. In many cases what happens with the first approach is that the content in effect drives out the design, whereas in the second case the design drives out the content. So the question then comes down to what is the course really about. Our simple test is that if we are willing to teach "Basic Principles of Design Morphology," or "Failure Analysis in Design," or "Design of Thermal Systems," and have most or all projects involve, respectively, no meaningful morphology, failure analysis, or thermal systems, and yet be outstanding design solutions, then we are teaching a real design course. On the other hand if the failure to include these elements meaningfully prejudices the project evaluation against the design, then we are really teaching an analysis course.

If a project experience is selected because it is supposed to exercise certain analytical skills or convey a certain specific discipline or content, then it must have a hidden "correct" answer or preferred set of answers. If it does, then it is not a genuine project experience for the faculty member, and then it almost invariably falls short for the students also.

• 7 Student competitions

We feel that the use of student contests is ill considered, even when they seem to produce good results. Contests are used because they are easy ways to generate excitement in the classroom. The problem is that in the excitement many of the "losers" get lost to the educational process and to the profession. There is also evidence that even the "winners" do not really win educationally. It is quite different to act to get something done rather than to act to best someone else.

Certainly the message that contests convey, of working competitively against your classmates, does not belong in a learning environment. We like the comment of the master of ceremonies of the 1992 Cotati (CA) Accordion Festival: "Remember, folks, this is a *festival*, not a contest."

III. SOCIAL ISSUES

The socialization and self-esteem aspects of the way design is offered in the university are important. In many ways design courses need to establish norms different from those currently in use in most engineering colleges. We need to encourage students to work together in teams, and not to compete with their classmates. They need to learn that it is okay and highly desirable to copy from others, i.e., they need to respect and practice reverse engineering and to take good ideas wherever they find them (assuming of course that they give due credit and do not violate any laws or ethical considerations.) They need to change their concepts of what it means to "cheat" and what it means to do one's "own" work in the context of design.

In his 1986 book titled *No Contest*, psychologist Alfie Kohn makes the point that contrary to common myth superior performance is not brought out by competition; in fact it usually seems to require the absence of it. He points out that we do not learn and work better when we are trying to beat others. We in fact do better when working with others or alone. He shows that there is overwhelming evidence that competition is almost never better than cooperation.

So why do people compete? Kohn feels that "We compete to overcome fundamental doubts about our capabilities and, finally, to compensate for low self-esteem." He feels a competitive system maintains low self esteem, and that even the winners constantly need more success and can never find such a system ultimately satisfying. These findings and ideas have important ramifications for design education, especially in regard to the use of:

1. design contests ... with winners and losers
2. design criticism ... of good and bad work, and
3. group versus individual design projects.

The next sections discuss each of these in turn.

• 1 Design Contests

It has become conventional to think of contests with prizes for first, second and third place—or in terms of gold, silver and bronze medals—yet little thought goes into the educational ramifications of this type of mentality. In fact these kind of prizes are meaningless. If one has a need to award prizes it is much more meaningful to award prizes on the basis of specific aspects

project: such as most creative use of materials, simplest design, most the spirit of the project, most sensational looking, to name a few.

We feel that if one wants to use design contests in education they should be in the spirit of fun rather than actual competition, and moreover any serious competition should only be in the sense of competing against yourself—that is trying to do one's personal best—rather than competing against your classmates. There is a common assumption that working toward a goal and setting standards are the same as competition. This is a false idea due to the fact that we mistakenly equate meeting a challenge with competition.

We attempt to foster a spirit of cooperation; this is more than simply the lack of competition. We attempt to structure cooperation so that students have to work together in order to achieve common goals. Successful completion of a task depends on each student and therefore each has an incentive to want the others to succeed. In our workshop we used both explicit and implicit methods to allow the faculty participants to experience the power of peer group cooperation.

• 2 Design criticism

We discourage labeling and rank-ordering, and in our workshop we do some exercises to give people the experience of how deadening these can be to the creative process (Faste, 93). We are especially concerned with giving students constructive feedback, and encourage the faculty ticipants in our workshop to practice criticism in a way that promotes itive action rather than withdrawal, deadening defense or low self-esteem. There is for example, the technique advocated by one of the Synectics groups [Prince, 1970]: first deal with what you like about the work, and then deal with the shortcomings in a way that encourages further effort and creativity (e. g., "I *wish* we could find a way to get the cost down" as opposed to "It is too expensive to make it your way!")

• 3 Group vs. individual projects

In our workshop we use group projects to give the participants an experience of the wonders and problems of working in design groups. Our experience with both the workshop participants and with many student groups is that on balance each individual gets a lot more from the other members of the group than if she or he worked alone. This assumes that the group is properly facilitated; someone should be available to assist with impasses and interpersonal problems. Small design groups do not need formal group leaders or coordinators—in fact they learn a lot by handling their own dynamics and scheduling. What they do need is an occasional impartial referee and a cheerleader when they are at a low point. In our workshop and in our classes we take some pains in setting up the groups so that they are balanced in terms of skills and personality. When properly arranged, the experience of working with others on a design project is one of the highlights of the workshop for our faculty participants, just as it is one of the highlights of their degree program for our undergraduate and fuate students.

We give a lot of thought to selecting the projects. Our experience is that you cannot go back to last year's project with this year's class. So one rule that we follow is always to use a new project. This is important for the faculty in order to keep us from knowing "the" answers, and also to make the entire process fresh for the students. We believe the medium is the message: if students are asked to take risks, the faculty should do the same. Sometimes it takes a lot of courage to abandon a winner and move into new untested ground. We do not always succeed, but we always learn and so do our students.

We give careful consideration to the size of the project groups. Individual projects are indicated for small tasks or for giving students specific sets of experiences involving manual skills or for thesis work. In our workshop we use individual work, two-people assignments, three-people assignments and four-person team assignments. Each has its uses, and we encourage faculty to experiment with different group sizes, as we feel this is an important variable in a design project assignment. Our experience is that for large involved projects team sizes of three or four are best.

IV. THE CREATIVITY WORKSHOPS

• 1 General philosophy

Several principles for conducting the creativity workshops are held in common by all the facilitators. Learning takes place as much as possible by personal action and direct experience rather than through lecture and problem set. Thus conventional lectures are used only to introduce basic theory and background material that will persuade the students to involve themselves more fully. Emphasis is on developing those visual, imaginative, emotional and sensory parts of the intellect and psyche neglected by the engineering curriculum's necessary focus on fact, theory and logic [deBono; Herrman; McKim]. This is done through both personal introspection and non-threatening feedback from other students. Such communications are enhanced by special two-person (dyadic) and group conversations, leading often to unconventional classroom arrangements and physical movements. To varying degrees all facilitators demonstrate safe techniques for helping students experience, express and trust their emotions in constructive ways that enhance creative problem solving and productive group cooperation. The combined behavior of the facilitators generates an environment in which creative potential can be developed and expressed. Finally, the very wealth of unconventional activities tends to generate implicitly the flexibility and spontaneity characteristic of most creative people.

• 2 Faste: Visual Thinking, Ideation and Craftsmanship

In addition to all these general approaches, Faste shows everyone how to visualize both kinesthetically and visually, that is, how to feel, see and draw [Edwards; McKim]. Many people initially experience their creative potential when they produce their first good drawing of a human face, and the improvement in portraiture skill of the participants in a very short time is one of the most remarkable results of the workshop. Faste also brings his experience in teaching Product Design to bear on idea generation [Gordon, Prince], constructive criticism and the construction of physical models.

• 3 Roth: Goals, Intention and Public Speaking

Roth's focus is on setting goals, clarifying intention and overcoming the obstacles blocking successful achievement [Roth]. His communication

nvolves guided individual introspection, verbal exercises and active ning, so he supervises the session on lecturing styles and their improvement. One of his strongest talents is the ability to set up and direct powerful psychodramas illuminating the universal experiences of the engineering professor.

• 4 Wilde: Subconscious Resources

Wilde applies psychological theories to the recovery of creative resources repressed into the subconscious by the intellectuality of the engineer's professional education [Perls; Hefferline & Goodman]. He supervises the personality type self-evaluations [Myers & McCaulley; Hirsch & Kummerow; Wilde] and demonstrates how type affects teaching and learning style [Kroeger & Thuesen]. Transactional analysis [Berne; Harris], the study of "games people play," is applied to both to the dynamics of design project groups and to the reanimation of repressed spontaneity.

• 5 Schedule

The Workshop is held during two five-day weeks with the intervening weekend free for rest and recreation. To allow for transcontinental travel, the first day starts in the afternoon and the last ends in the morning, but the time is made up during a late session for finishing the project. Actual techniques are demonstrated on the fly as needed, rather than systematically, and there are always dramatic unplanned events growing out of unique circumstances.

first week is devoted to developing self-awareness and individual ativity, using personal projects from back home to practice on. It is also the time for sharpening lecturing and communication skills while getting acquainted with the other participants and learning when and how to trust them.

In the second week teams form to design and build a small hands-on project requiring much interaction and cooperation. This provides a vehicle for learning about ideation techniques, group dynamics and getting things done in a short time. The friendly (rather than cut-throat) competition, late night work session, uproarious presentation and vigorous celebration bring out surprising amounts of suppressed creativity, ease beneficial personality shifts and generate *esprit de corps*. The farewell session settles unfinished business, seals new friendships and builds a support network helpful when they go back home.

V. MYERS-BRIGGS QUESTIONNAIRES

• 1 Self-evaluation

As part of their study of personality and group dynamics, participants, both at the beginning and near the end of the workshop, voluntarily filled out a Myers-Briggs Type Indicator (MBTI), a self-evaluation questionnaire [Myers & McCaulley] used increasingly by educators and organizational behaviorists. These questionnaires have great value in that their use ides the group with a direct experience of the fact that people see the orld in very different ways. Often, what seems correct and natural to one, seems wrong and unnatural to another. By incorporating this experience into their lives the participants are better able to deal with their colleagues, students, administrators and families. An interesting measure of the workshop's impact on the participants and facilitators was obtained as an accidental by-product of these questionnaires. The scores indicated a statistically significant improvement in a certain creativity measure. This is being reported elsewhere [Wilde]. Here we present a description of the small but measurable changes in outlook detected.

On the average, the participants entered with the attitude of a *planner:* introverted, slightly imaginative, logical, and preferring organization to flexibility. After two weeks the average participant answered their questionnaire as a *problem-solver:* less introverted, more imaginative and open to humane considerations, and increasingly spontaneous.

The three authors, here called the "facilitators," also registered detectable changes. On the average they began as *innovators:* extroverted, imaginative, a bit on the logical side, and willing to sacrifice organization for improvisation. At the end, although their extroversion was unchanged, their imagination, willingness to use their feelings, and flexibility increased about as much as that of the participants, generating an average personality more like that of a *facilitator*—not surprising considering the workshop techniques.

• 2 Psychological Space

As shown elsewhere [Wilde], the set of all possible MBTI scores can be mapped to a bounded four-dimensional vector space, here called the *psychological space* . Having four dimensions, it can be represented as in Fig. 1 by two planar graphs with the MBTI variables as axes Perception/Judgment, Sensing/iNtuition; Introversion/Extroversion, Thinking/Feeling. The initial average participant score is represented by the circles, marked "*p*," in the two parts of Fig. 1, and the arrows emanating from them show the change in two weeks. The facilitators are tracked in the same way by the squares and the arrows marked "*f*."

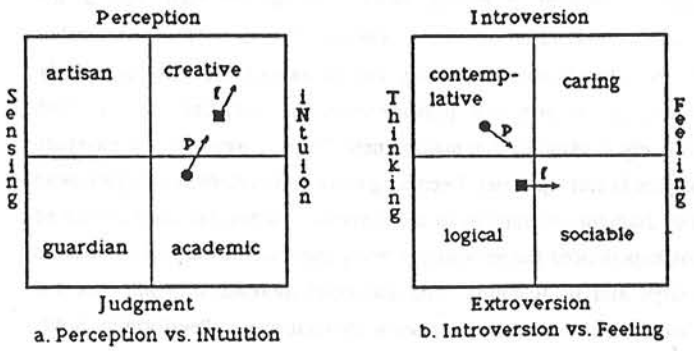

Figure 1
PSYCHOLOGICAL SPACE

The four quadrants of both graphs are labeled with adjectives culled from the personality-type literature summarizing the characteristics of people with corresponding scores. Thus the plot of Fig. 1a shows the participants' movement from the *academic* quadrant into the *creative* quadrant. The plot in Fig. 1b shows a shift from Thinking toward Feeling that takes the facilitators across the border from the *logical* to the *sociable* quadrant while the participants move through *contemplation* toward *sociability.* As

they get to know everybody, the participants naturally become less introverted, whereas the extroversion level of the facilitators, already on their home turf, remains the same.

• 3 Personality Type Space

A clearer interpretation is obtained by rotating the space to make the axes line up with the personality types for which there are one-word descriptors (e. g., "planner") closer to everyday meaning than MBTI technical terms such as "iNtuition." The negative side of each axis corresponds to the completely opposite type on the MBTI scale. For instance the negative side of the "planner" axis is "performer," as shown on the horizontal axis of Fig. 2b. As will be shown in a mathematical sequel being prepared for the 1993 ASME Design Theory Conference, a system of four orthogonal axes, each representing an opposed pair of personality types, can be formed: (1) innovator/conservator, (2) persuader/crafter, (3) planner/performer, (4) idealist/manager. Fig. 2 displays the result, including plots of the participant and facilitator scores in this rotated system.

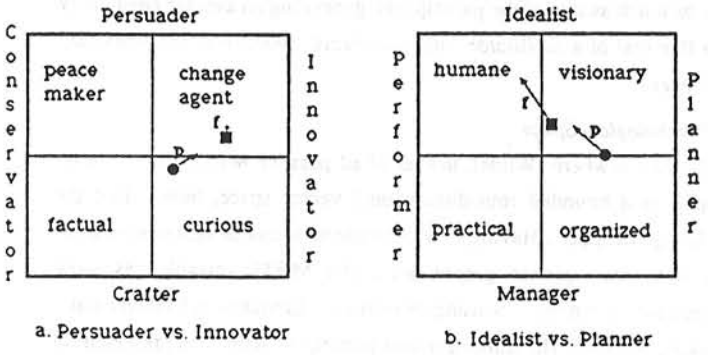

Figure 2
PERSONALITY-TYPE SPACE

Fig. 2a shows this *personality type space* in which the average participant increases in innovation, moving toward the steadily high value of the facilitators. The taste of all for persuasiveness over craftsmanship increases, although not significantly. Fig. 2b tracks everyone's comparably increased preference for performance and idealism, as opposed respectively to planning and management. Note, however, that the average participant is still a planner. Becoming more of a performer may just mean greater dramatic interaction in the classroom, a natural consequence of having experienced the workshop's many somewhat theatrical approaches to design and its teaching. The universal increase in preference for idealism, which Kroeger & Thuesen characterize as "performing noble service to aid society," is perhaps the most surprising effect of the workshop, whose overt goal was only enhanced creativity. In hindsight, however, humane idealism is certainly a characteristic, along with creativity, one might hope to find in educators—especially those who teach design.

• 4 Qualifications

The analysis preceding only involved averages; about half the individuals can and did react differently according to their history and personal needs. A quarter of the total reported little or no change, whereas the remaining quarter experienced remarkably larger transformations more or less in the directions indicated. Although statistically significant, the average changes were moderate considering the range of human preference possible. No follow up studies were conducted to see if the movements were temporary, permanent, or even, as we would hope, the beginning of even greater development.

VI. CONCLUSIONS

This paper has argued that the creativity and cooperation upon which good group design depends requires a humane atmosphere. It described a workshop for professors organized according to principles fostering such an ambiance. Self-measured personality changes, upon analysis, indicate definite increases not only in the creativity which motivated the workshop, but also in the taste for performance that lends color to the classroom and in the idealism that motivates attention to the human factors of design and teaching. Design projects can develop the non-analytical but necessary portions of the intellect unavoidably neglected by the rest of the engineering curriculum. Hence it is vital that design education be done very well. Such workshops seem to be an effective and efficient way to convert professors educated primarily for lecturing and research into true facilitators of design.

Acknowledgment. The workshops were supported by the National Science Foundation through the American Society of Engineering Education, and were administered by Professor Michael Rabins of Texas A. & M.

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