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Managing Creativity: A Creative Engineering Education Approach

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Abstract

Managing Creativity is the title of a course originally developed by an experienced manager of creative teams for training industry executives. However, it has been adapted successfully to teaching the end-to-end process of engineering to college students. The paper describes the Creative System which is the basis of *Managing Creativity*, outlines the class structure and subjects covered, and describes the overall process. Positive student evaluations and continued demand for the course are used for assessment. The course covers all aspects of a creative enterprise, from assembling a creative team, to generating original ideas, to alignment of the team and its customers and suppliers, to planning, design, risk management, production, and deployment into the market or operational environment. All classes include business planning and a hands-on engineering project (usually designing and constructing robots). The role of evaluation and communication are stressed. The course provides an important overview and hands- on experience normally not available to engineering students until their senior design course.

Background

Managing Creativity is a concept developed based on the author's 35 years of experience in a variety of creative enterprises, including management of NASA's $150M per year Mars Exploration Program and of the Pathfinder microrover, Sojourner Truth, which roamed Mars in 1997. In 1997 and 1998 the author and a collaborator (Alice M. Fairhurst, a counseling psychologist with expertise in personality type), developed a short course in how to manage creativity for NASA's Jet Propulsion Laboratory in Pasadena, California. The course was presented about a dozen times to mixed groups with jobs ranging from secretaries to top managers.

After retirement from JPL in 1998, the author became (in the fall of 1999) Assistant Dean of Engineering at the University of Oklahoma, where she transformed the short course into a three credit-hour class open to engineers and other disciplines. Since then the course has been taught in a variety of formats: as Introduction to Engineering (for freshmen); as an upper-division and graduate level course (primarily to engineers); as an intensive "Intersession" class (8 day and 10 day format); and as a short course for faculty. The class is based on a "creative system", developed by the author, which codifies the techniques she developed over a 30-year management career. The class builds on the NASA Systems Engineering process, which was developed by a team, led by the author in the early 1990's[1]. Many references (see Bibliography for a sample) were used to support the experienced-based course design. While there are numerous courses available in elements of this class (e.g. senior design classes), to the author's knowledge there are no other classes which integrate all the pieces into an overall process for managing creative enterprises.

Collective Creativity

Managing Creativity focuses on creative enterprises, in other words, how to lead, manage and/or work in a creative team. Creativity is generally viewed as an individual pursuit, and of course, it can be, but groups can produce things which one person can hardly imagine. Spacecraft, cathedrals, good schools, parks, medicines and computers all result from group or "collective" creativity. Plays, exhibitions and concerts are enabled by individual creativity, but they are made manifest by the creativity of a group. A well-conducted orchestra produces music more thrilling than the sum of the individual skills of its musicians.

Creativity is easily recognized in the worlds of art and science. But creativity is needed everywhere. Today's world is moving at an ever-faster pace. Business is increasingly competitive. Individuals and organizations are being prepared by changes in society to accept and support creativity, but organizations are going to have to change their practices in order to take full advantage of the creativity of their people.

Group creativity begins with an idea—sometimes the vision of a single person. Usually a creation is built around a mental template, structured from experience or training; pure creation occurs rarely, if it exists at all. The best individual creations aren't spontaneous eruptions of an idea. They result from often frustrating trials that ingeniously combine known concepts and things into original forms. In other words, productive creativity is hard work. In groups, visions are shaped and structured into reality through a series of processes that consciously or unconsciously use tools, resources and people in complementary or competing ways. Successful

creative teams produce useful, saleable, quality products and services.
The College of Engineering at the University of Oklahoma is in the business of developing engineers who can contribute to and lead creative teams[2]. The College has conducted numerous formal and informal surveys of its alumni, and of industrial managers. Trends which emerge from these surveys indicate that newly graduated engineers (from most engineering schools) are well trained in their disciplines, but lacking in the ability to apply this training to group enterprises. They need skills in communication, teamwork, understanding of business processes, and awareness of and appreciation for other cultures – which translates into an ability to work in global enterprises. They also need to understand and appreciate how their discipline integrates with other disciplines (within and without engineering) to enable creative enterprises.

These are also traits which the author noticed were deficient in the aerospace industry, leading to a general climate of overruns and failures in the 1990's[3,4,5]. The Managing Creativity course was initially created to address these deficiencies.

A Creative System

People say: "Managing *creativity*? Isn't that an oxymoron?" In fact, the ability to manage creativity is the key to future prosperity for organizations, companies and governments. Harnessing collective creativity to produce useful, saleable and innovative products can be made a lot more effective by using a process that specifically addresses all the phases of a product life cycle, and all the tools available to create and bring the product to reality. Such a creative process can be visualized as a system of interrelated elements, as shown in Figure 1, below.

The elements around the ellipse in Figure 1 correspond to phases in a product lifecycle, but the double-headed arrows indicate that they can't just proceed in a step-by-step process. They must continually interact and each element affects, and is affected by, the others. A brief description of each element is included with the detailed course description, which follows.

Balancing Acts

A key to the management of creative enterprises is to maintain balance. Too many popular management books imply that a simple application of a single principal can result in good management. But it's clear that a key management job is to constantly balance the competing demands and constraints on a creative enterprise. Some dimensions of this balance can be illustrated with diagrams called "Balancing Acts", as shown in Figure 2. Too much or too little of a good thing, like speed or control or risk-taking can destroy the effectiveness of the creative enterprise. On the vertical axis is always "performance" which boils down to how well the enterprise performs in terms of the metrics chosen by the enterprise itself, usually bottom line profitability. The horizontal axis represents the extremes of the parameter, from too little to too much. In the middle is the Goldilocks point – it's JUST right.

Figure 1

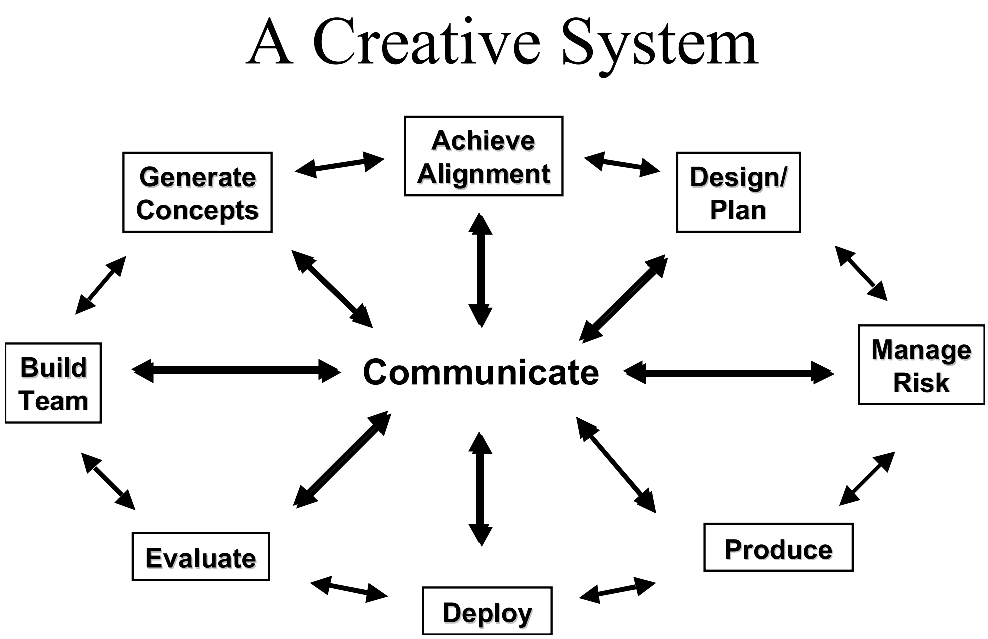
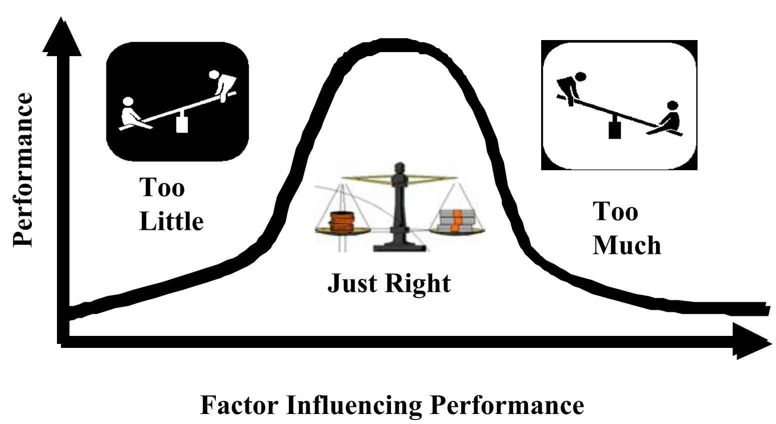


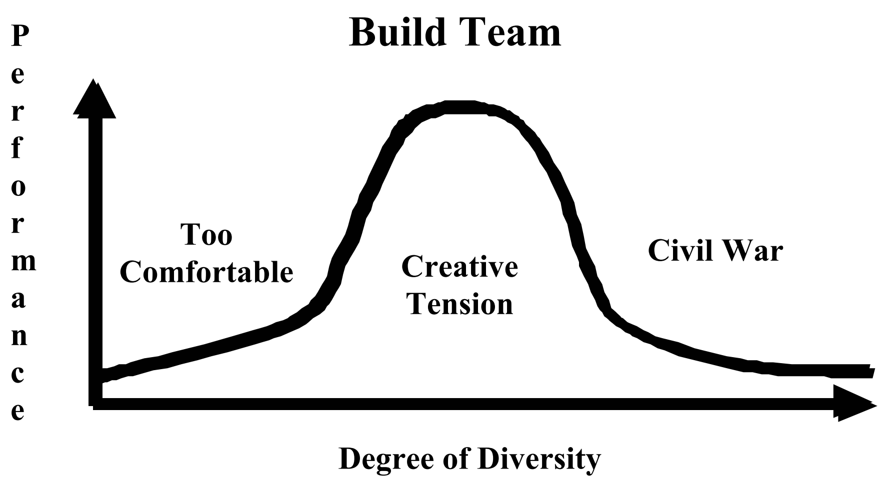
Figure 2

Balancing Acts



Examples of balancing acts are used for each element of the course. For example, in Build Team, the value of diversity to produce creativity is emphasized. Diverse teams are creative teams.
However, diverse teams are harder to manage than homogenous teams. Many more people-skills and much better communication are required to retain the focus and effectiveness of a diverse team. This is illustrated in Figure 3.

Figure 3



The Managing Creativity Class

The class features one or more lectures in each of the elements of the creative system. In addition, there are lectures on ethics and personal creativity. The lectures are presented in power point format and are posted for download from the Internet on the University of Oklahoma "Coursenet" system. In the Introduction to Engineering classes students are required by College policy to have laptop computers. Students can follow the lectures on their computers, and some take notes on the power point slides. In other classes, laptops are required only of the engineering students.

Each lecture is broken up with exercises to illustrate the concepts being presented. Additionally, in each class the students are broken into teams (usually four to six in classes between 15 and 40 students) which are as diverse as possible in terms of personality, gender, culture, and skill sets[6]. The teams are later combined into larger groups which become a "business"[7]. There are team midterm and final reports and presentations, as well as individual exams and homework assignments. Peer grading is also used. The lectures are lavishly illustrated with actual examples, many drawn from the author's personal experiences, particularly as the leader of the

Pathfinder microrover team.

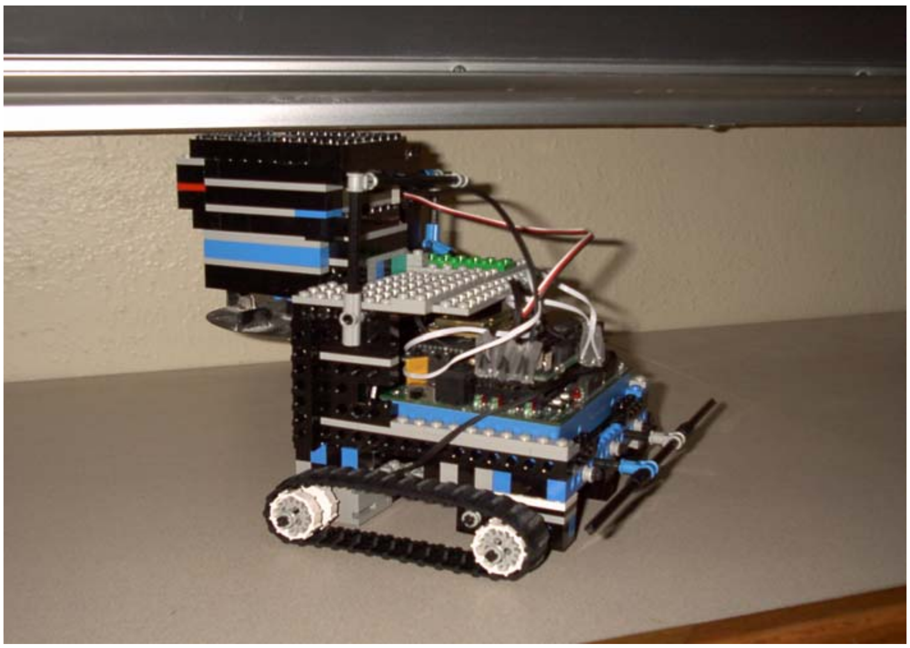
The elements of the creative system are used as follows:

Build Team – Build Team: Collective creativity requires a team with a diverse set of skills. The creativity of the team is enhanced by other types of diversity such as personality type, creative style and experience level. “Building” a team means not only assembling the right set of people to do the job, but the process by which the team grows in capability and alignment throughout the process of collective creativity. In the course students are encouraged to appreciate and utilize the diversity of their teams and the contribution of the diversity to creativity and productivity. However, since diverse teams require more management and communication to break down barriers and misunderstandings than homogenous teams, exercises such as how to conduct productive meetings are included. The microrover team is the focus of lectures on how to select and manage a team with diverse skills and experiences. One diversity exercise is to form teams by mixing personality types[8] and have them notice the advantages and difficulties of working with people unlike themselves.

Generate Concepts – Generate Concepts: Where do good ideas come from? Usually from a single person, but they will quickly be enhanced through the process of collective creativity. “Generate Concept” is where people tend to think that creativity occurs, and, indeed, a creative enterprise needs to start with a creative concept. However, a creative enterprise needs creativity at all stages and the concept evolves throughout the process. In the course exercises in creativity build on the use of models[9] and metaphors. Techniques such as brainstorming and multi-voting are introduced. The four teams each identify (completely arbitrarily) a problem they would like to solve. They then use creative processes to develop solutions to the problems[10], and group processes to select one of the solutions. Next, the four teams are combined into two “business” teams, which must spend the rest of the semester developing a business to implement that solution[11]. (Use of large and small teams illustrates the need for different management techniques depending on team size and complexity.) Examples of “businesses” which have been developed in various classes include: companies to harden overly soft water in the student dormitories, to create textbooks on CD ROMS, and to design advanced educational techniques; and companies to create robots for taking pictures at student parties, fighting fires, and kicking field goals.

In the freshman and upper class courses (but not so far in the faculty classes) each business must then develop a concept for a robot to illustrate some aspect of the business. LEGO robot kits provided by the KISS Institute for Practical Robotics (http://www.kipr.org) are used for building autonomous robots. These robots use LEGO RCX computers which are programmed in a variant of the C computer language to perform tasks without human intervention[12]. Therefore, at least some students on each team must bring laptop computers to class with which to create and download programs to the robot's computer. Since most of the students to date have been engineers there are ample laptop computers. All students are required to learn how to program the robots. Figure 4, below, is an example of a team-built LEGO robot which is a prototype for spreading fertilizer on lawns.

Figure 4
"Agribot"



Achieve Alignment – Alignment is required within the creative team, between the team and its customers and suppliers, between the team and other teams in an organization, and between the team and its management. Alignment means agreement between the parties not only as to the vision for the enterprise, but also alignment between the vision and the resources required to achieve it. A failure to align properly is responsible for many cost overruns or product delivery problems. Alignment is required at every stage. The teams in class must align themselves to choose a problem and a business. They must align around their plans, designs, cost estimates, and financial plans. In particular, they must align around the jobs. Who will do which part of the project? Who is responsible for which part of the final report? Who makes sure that all the parts fit together? They must also identify customers and suppliers with which they must align. For example, they must follow the instructor's rules concerning the use of the robot kits. Various alignment exercises are conducted throughout the course[13].

Design/Plan – The first step in turning a creative concept into reality is to develop a design and a plan. The design and planning process forms the basis for the implementation of the creative enterprise; as well as for the "contracts" which are the basis of a formal alignment. Design and planning are intimately intertwined. The teams begin by developing strategic visions for their businesses, including mission statements and high-level goals[14]. Tactical or business plans are developed to guide implementation of their business strategies[15]. Teams are required to develop business plans considering finance, marketing, research and development, production, and product or service deployment into the operational environment or the marketplace. In addition, they must plan a project to design and build their robot[16,1718]. They learn to break a problem down into individual elements and to build up overall solutions to the problem from possible solutions to the elements (the systems engineering process). They develop work breakdown structures and assign team members to the various work elements. Cost estimates (in terms of work-hours for the team) are made for all aspects of the business and project[19]. They use rapid prototyping as a design tool for their robots – build and try, rebuild and retry. Tradeoffs used in the design of both the robot and the business must be documented. Techniques for making tradeoffs, such as matrices and decision trees, are taught[20]. Each team must illustrate their designs.

Manage Risk – Creative enterprises are inherently risky. Management of this risk, throughout the creative process, is key to success and allows creativity to be channeled. Risk management must begin at the earliest stages of the process and is an integral part of alignment, planning, production and deployment. Each team must develop a risk management plan. Risks to the business and the robot project are identified and their severity and likelihood determined[21,22]. Risks are identified in the categories of failure risks (complete or partial failure of the business or project), performance risks (the business or project does not perform to expectations), and safety (to humans) risks. Actions to mitigate the risks are determined. A risk management process is taught which requires estimation of resources (in work-hours) for risk mitigation (usually as a percentage of the expected work-hours for the project). As the projects proceed, the teams keep track of the resources used vs. those planned. Failures and setbacks are documented. Differences between the midterm plans and the final plans and results are noted. The biggest risks in each of three categories (performance, technical, and safety) are identified for each phase of the project.

Produce – A creative enterprise is set up to produce something (which may be a service). Production may be carried out by anything from a laboratory experiment to a production line to employee training, and the ability to produce the creative product or service must be considered at all stages of the creative process. The teams develop plans for production of their product or service[23]. They develop plans to produce both their business product and their in-class product.

For example, the team whose business was to produce textbooks on CD's developed a plan for how their business would work with textbook companies to get the rights to put their textbooks on CD's. They also had a plan for how their robot (which they used in class in a "commercial" for their product) would be built, and then they built the robot to the plan. Techniques taught in this element include flow-charting and probabilistic decision trees.

Deploy – Deployment can involve putting a product into the marketplace and providing maintenance support for it, or it can be merely handing a product off from the laboratory bench to the prototyping process. In the first case the deployment phase can be years long, in the latter case it can be merely the start of the next cycle of development. The business presentations made by the teams including elements such as servicing and maintenance plans, warranties, and product recycling policies[24]. The actual deployment of the robots and the business plans is done in the form of midterm and final reports and presentations. Ten-to-twenty page reports are written at midterm, and presentations of the reports, plus demonstrations of the robots, are made. The midterm critique (by both the instructor and the other team) of these reports and presentations usually produces remarkable improvements in the final products. Deployment also includes marketing plans.

Evaluate – Proactive, efficient and constant evaluation is key to managing a creative enterprise. Evaluation includes selecting the right metrics, measuring them, and having the appropriate skills to assess how the enterprise is doing. Evaluation is an inherent part of the risk management process. Rapid prototyping[25] is a major focus for evaluation. In the class, rapid prototyping involves building a complete system relatively quickly (a plan, a report, a robot), and then evaluating its performance. Lessons learned are used to rewrite/redesign/rebuild the next system. This technique is widely used to develop initial products such as software (alpha and beta test versions are late stage examples of rapid prototyping) and products such as automobiles (future production models which are tested on the racetrack). It can also be applied to services, as the ubiquitous "this call may be monitored for quality" illustrates. The value of rapid prototyping in class is usually best illustrated by building several versions of the robot. The final design is often quite different from the initial design (e.g. switching from wheels to tracks or completely re-designing the demonstration objective). Evaluation techniques such as decision trees are taught.

Personal Creativity and Ethics – Ethics[26] is a required element of the Introduction to Engineering class, and an ethics lecture is also included as a refresher in the advanced class. Examples of difficult ethical situations used in class include the Challenger accident, the Tacoma Narrows Bridge failure of the 1940's, and the failure of the two Mars Surveyor 98 missions[27]. (The last example is from the author's personal, bitter, experience.) Personal creativity is addressed through exercises where teams of two interact to reflect on what enhances and what detracts from each person's ability to be creative.

Communicate – The glue of the creative system is communication, which must be constant, effective, information rich, and well managed. Communication technology is burgeoning and the extraction of information from data is becoming ever more difficult, but if they can be dealt with effectively these factors can be used to move an enterprise forward with great speed. Communication techniques are illustrated throughout the class[28]. Meeting protocols and structures are described and tested. Electronic communications are used extensively for the class. In addition to lectures and other information being posted on the Internet, instructor and student communication depends heavily on e-mail. Chat rooms are set up on the web site for use in team coordination. A lecture focuses on the future of communications and on the risks attendant on new technology (from animosity due to ill-advised e-mails, to privacy violations). The midterm and final exams are taken (in the case of engineering students) on their laptops, with the results either being e-mailed to the instructor or posted on the web site in real time.

Introduction to Engineering (A Managing Creativity Class Example)

Managing Creativity has been taught dozens of times to students ranging from adult managers of high tech corporations to freshmen in college. Criteria for assessing Managing Creativity vary somewhat by the type of class. All of the OU classes are graded on the A-to-F scale. Assessment of the effectiveness of the class is done primarily by questionnaires completed by the students. All of the classes have received excellent evaluations, except that freshman classes score somewhat lower than those for more mature students. This is a common phenomenon.

For brevity, this section will focus on the Honors sections of the introductory freshman engineering class (ENGR1112) taught in the fall of 2000 and 2001. The Honors College at OU is for high-achieving students. Forty percent of the Honors students are engineering majors. Small class sizes (21 or less) are required to qualify as an Honors class. ENGR1112 is a 2-credit-hour, required, first course for all engineering majors. Students must have passed or be enrolled in Calculus 1 to take ENGR 1112. The objectives of the Introduction to Engineering course are for the students to:

- Acquire proficiency in basic computer skills (e.g. word processing)
- Develop problem solving skills
- Develop written communications skills, especially technical reports
- Develop interpersonal skills for working in a group environment
- Understand what is involved in the engineering design process including problem definition, literature research, and design evaluation.
- Confront and deal with professional issues including ethics, types of engineering, curriculum requirements for the different engineering majors, use of library and other resources, and use of the Placement Services Office.

Virtually all of the ENGR1112 classes use one or more projects to focus the student learning in the first 5 categories, above.

A first computer course, ENGR 1001 - a one-hour lab course - is also required. In some cases ENGR1112 and ENGR1001 are taught concurrently. In the case of Managing Creativity, since programming is required for the robots, this combination was used for the fall 2001 Introduction to Engineering Honors course, effectively creating a 3-hour course. A single instructor (Shirley) taught the first course with a teaching assistant – a computer science senior who had previously taken the Managing Creativity course. The second class utilized two teaching assistants – sophomore computer engineering majors - who had taken the first ENGR1112 class in 2000. The sophomores were very effective instructors and tutors for the freshmen.

Since Managing Creativity, as taught with laptops, already focussed on the first 5 objectives (above), it was easy to add lectures on the different majors. Most of these lectures were by faculty in the various Schools. Use of the Internet was emphasized over use of the library, and use of the College of Engineering Advising Center was stressed over the use of the Placement Services Office. Since all of these students had laptops the ENGR1112 courses were very computer-intensive.

Electronic exams were given at midterm and final. In the first course the exams were put onto floppy disks (provided by the students) and the finished exams downloaded to the floppies and handed to the instructor. In the second course, exams were provided on paper and the finished exams were e-mailed to the instructor and the teaching assistant. In the first class the students were taught the variant of the C language to program the robots. In the second class, which was integrated with the one-hour programming lab, they were introduced to the actual C language and programmed in C, as well as programming the robots in the variant of C. Both classes used LEGO robots.

Assessment

A formal survey was used for evaluations in these two courses. In this survey students rate the class (actually the instructor) on the preparation, teaching style, etc; on the degree to which the class contributed to the student's development; and on the effectiveness of the laptops. The scoring is from 5 (Agree Strongly) to 1 (Disagree strongly), so lower scores are better. Reports are prepared which compare the instructor's scores for this course, to historical scores of other instructors in her department and to all instructors in the College of Engineering, for that course.

For the fall of 2000 class the average scores for the instructor were somewhat worse (3.545) than those of either the department of Aerospace Mechanical Engineering (3.73) or the College of Engineering (3.88). The main "downers", i.e. elements which were substantially worse than for the Department or College, were that the exams were not fair and relevant to the material (3.5), that basic science and math principles were not taught (which was not the intent of the course) (3.23), and that effective writing was not taught (3.28). In general, the students did not appreciate the use of laptops and the survey results corresponded to feedback in the class.

For the second class, in the fall of 2001, more time was spent reviewing material before the exams, and more writing was assigned. Many fewer complaints were expressed in class about the use of laptops. The scores for the second class, in the fall of 2001, were compiled by the Honors College on a 5 to 1 (best to worst) rating scale. In this case the comparison was with other Honors courses in the fall of 2001. Again, the average scores for this Introduction to Engineering class (3.94) were lower than the overall Honors course evaluations (4.24). The data does not directly compare freshman evaluations but includes all four years. Only one category – oral communication skills – was ranked higher for Introduction to Engineering than for other Honors courses, and it was significantly higher. The main "downers" were in writing skills (3.35), fairness in grading (3.65), and individual attention by the instructor (3.6).

As might be expected of an Honors course, grades were high:

Fall 2000: 20 A's, 1 B
Fall 2001: 25 A's, 1 B

Since an objective of the class is to retain students capable of handling the rigors of an engineering curriculum a question on the final exam is: "What engineering career (if any) are you most interested in and why? If you are not sure, which ones are you vacillating between? If you are not interested in engineering anymore, what do you want to major in, and why?" The results were:

Fall 2000: 19 retained in engineering, 1 transfer to Business, and 1 undecided.
Fall 2001: 23 retained in engineering, 1 transfer to English, and 2 undecided.

The College of Engineering is currently developing a database to investigate retention issues. Part of this effort will be to follow up with these Honors freshmen to see how many were actually retained.

Conclusions from Assessment

Managing Creativity is highly regarded by students at all levels, both college and professional students, with the somewhat lower exception of the freshman engineering classes in the fall of 2000 and 2001. This course demands a great deal of independent work and thinking and is much less structured than high school courses, and the author suspects that this approach to Introduction to Engineering may be overly difficult compared to other approaches which cover less breadth of material. Attempts will be made to survey these freshmen in later years to determine if their evaluation of the course changes in the perspective of more engineering courses, and if their retention is affected. In any event, the course will be made more structured for future freshman classes.

Future Plans

Managing Creativity in the ENGR4510 format will be taught as a regular 3-credit hour technical elective in the spring of 2002; as 3-credit hour technical elective in the spring Intersession (with Alice M. Fairhurst); and as an intensive, 3-credit hour class for Masters students in Telecomputing at OU's Tulsa campus.

Managing Creativity is already open to non-engineering students at OU. The next step is to qualify it as an upper division general education course. There is consensus in the OU College of Engineering, based on inputs from alumni and their employers, that the subjects covered in Managing Creativity are important for all engineers. In addition, there is considerable interest among non-engineering students in these skills, so creating a general education course will make the course available to a much wider variety of students. This will greatly increase the number of classes required and will necessitate the development of new instructors. The most likely source of instructors for the course is the School of Industrial Engineering, for which Managing Creativity is already an elective in their new Engineering Management Master's program.

Evaluation of the freshman classes vs. older students indicates that the course should probably be offered at no lower than second semester sophomore and preferably the junior level. Since the Managing Creativity general education class will be designed to prepare students for experiences such as student projects (e.g. building cars and robots for competitions), research experiences, and professional internships, it is desirable to present it as early as students are prepared for it.

A book on *Managing Creativity* is purchasable on-line (http://www.managingcreativity.com). It was published on-line in 1997. However, it does not reflect the current structure of the course, so it is not used as a textbook. The book is being rewritten for possible print publication. In addition, the book is being used as a prototype for a new electronic textbook process being developed by a company founded by an OU Computer Science professor. Successful development of the e-book version of Managing Creativity will enable the course to be offered through distance learning and at other universities.

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