'APPLYING TQM IN THE IE CLASSROOM: THE SWITCH TO ACTIVE LEARNING*

Larry J, Shuman, Cynthia J. Atman, and Harvey Wolfe
Department of Industrial Engineering
University of Pittsburgh

ABSTRACT

In applying total quality management to the university environment, we have focused on one particular aspect of the educational process - how we teach and how students learn. Drawing upon the work of Felder[1], Smith[2] and Evans[3], we realized that our methods of teaching, and the resultant student learning could be substantially improved. Consequently, we have turned to various active and cooperative learning strategies in the conduct of our industrial engineering classes. While "active learning" has always been utilized for senior design capstone courses, it is now replacing "straight lecturing" as a more effective learning format for students. We describe-four undergraduate industrial engineering courses and how each has been converted to a primarily active learning format. These are "Modeling with Computer Applications" (first semester, sophomore); "Operations Design, Planning and Work Measurement" (second semester, sophomore), "Human Factors Engineering" (first semester, junior), and "Total Quality Management" (junior/senior elective). We discuss how we introduce students to different learning styles, teamwork, provide team training, address conflict resolution, utilize the world wide web, address "real" problems, use the computer for problem solving, introduce ethics, and stress written and oral communications skills. We also discuss issues involved with grading team assignments, maintaining accountability, and student evaluation and assessment.

In the "Modeling" course, students learn how to approach, model, and solve unstructured problems, and then use the results to make decisions. In doing this they use the computer as a problem solving tool; refine their programming skills and learn how to work as part of a team. As their first industrial engineering course, it is designed to challenge the student but also be fun. Grades in this process oriented course are based on team assignments, homework, and class participation; there are no exams. The "Operations Design, Planning and Work Measurement" course builds upon the first course. Students learn and apply the basic IE concepts and thought processes to a series of unstructured problems. Several plant trips are used to provide a first-hand introduction to the IE at work. In the "Human Factors" course, students further delve into issues of behavior, motivation, and ability in the design, development and operation of systems and components. Unstructured team projects are used to enhance learning. The "TQM" course introduces the student to the philosophies of Deming, Crosby, Juran and Kaizen and the spectrum of TQM tools and techniques for problem solving. Again, unstructured team projects are used.

INTRODUCTION

It is now accepted that engineering education is at a crossroads. A number of forces are causing us to reexamine what we are about and where we should be headed. As engineering educators, we will have to become both more flexible and more effective in how we prepare students for the next century.

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For the past few years, the US has been in a period of slow economic growth which, in combination with the intense global competition and the end of the cold war, has resulted in changes in the nation's priorities. At the same time that defense activities are declining, the need for industry to become more competitive in the world marketplace has caused major restructuring. Industry is now focusing on customer satisfaction, market share, quality, product and process improvements, value creation, productivity, time to market, and return on investment. Richard Morrow, Chairman of the National Academy of Engineering, believes that these same concepts have applicability in engineering education:

> *Global competition is as much competing intellectually as it is competing in the production and marketing of commercial products and services. In many ways it is more threatening competition, because the nation that can develop the best engineering talent is in possession of the core ingredient of comparative economic and industrial advantage*

Indeed, US higher education is rapidly approaching the same position that US industry occupied a decade ago - poised for a maj or restructuring and shake-out. Already, there is clear evidence that many US corporations seek their engineering talent wherever they can find it throughout the world. Engineering design quality, low-cost engineering services, and responsive engineering production capabilities are determinants of where engineering jobs will be found[5]. Combine this with the very tight, and even shrinking state and federal budgets, and attitudes among universities will change. Increased calls for improved effectiveness, use of total quality and continuous improvement approaches, and business-orientation among academics are likely to grow[6].

Our international competitors value flexible teams with multi-talented members in place of multiple tiers of management. Industry has recognized this and is putting tremendous emphasis on TQM, CPI, cycle time reduction, the elimination of management layers and their staff, and self-managed work teams. Team goals, team contributions, and team rewards are beginning to supersede individual goals and contributions To Larry Monteith, Chancellor of North Carolina State University and an engineering educator, international competitiveness means that engineering graduates must be industry smart. Understanding the factors which provide the trade-offs and decisions that provide competitive advantage will be expected by industry[8].

This intense competition is manifesting itself in another way; i.e., a growing competition among engineering schools for students, sponsored research grants and contracts, and consequently, survival. As US universities, faced with decreasing tuition and public funds and increasing costs go through "strategic planning" exercises, the future of a number of smaller engineering schools and programs will become problematic. Indeed, such a shakeout may already be occurring, as a number of smaller engineering departments, including many industrial engineering programs have been merged into larger departments as part of academic "downsizing" exercises.

Within the University of Pittsburgh Industrial Engineering Department, we have met this challenge by redesigning a number of our courses. Our objective is to make them more relevent, more interconnected, and more focused. As a result, we have moved away from straight lecturing to an active or cooperative learning format in which the role of the instructor has become more like that of a coach or facilitator. In doing this we have adapted methodologies and educational philosophies from several well known engineering educators including Richard Felder (North Carolina State), Karl Smith (Minnesota) and Don Evans (Arizona State), all of whom presented workshops at Pitt.

While active learning concepts have been introduced into a number of departmental courses, they are extensively used in" fours courses: *IE 1021: Modeling with Computer Applications* (first semester, sophomore); *IE 1054: Operations Design, Planning and Work Measurement* (second semester, sophomore); *IE 1061: Human Factors Engineering* (first semester, junior); and *IE 1076: Total Quality Management* (junior/senior elective). These courses build upon two freshman engineering courses that first introduce the student to such concepts as data analysis, unstructured problems and working in teams. Each of these courses will be described below.

MODELING WITH COMPUTER APPLICATIONS

The first course in the IE sequence, Modeling with Computer Applications, uses Smith, Starfield and Blelock, *How to Model It - Problem Solving for the Computer Age.* [9] This text has been specifically written to introduce the student to cooperative learning concepts. Students also learn to utilize the World Wide Web as a resource for information gathering and learning.

Picking up from the freshman courses, the student further learns how to approach, model, and solve unstructured problems, and then use the results to make decisions. In doing this, the student uses the computer as a problem solving tool; refines his/her programming skills and learns how to work as part of a team. In addition, the-student also examines such diverse topics as engineering ethics, different learning styles and preferences, and is first introduced to total quality management (TQM). This course is meant to be challenging, but fun. The emphasis is on creative and logical thinking, problem formulation, making assumptions, building models, developing heuristics to achieve solutions, and using common sense. The student is taught that problem solving is as much an art as a science. Consequently, there is never one right answer, although there are many wrong answers.

As a cooperative learning class, much of the actual problem solution is done in class and class participation is extremely important. Rather than exams, the entire class experience is considered as one, long exam. The more the student puts into this course, the more he/she gets out of it. The final grade is based on three group modeling projects, three individual computer programming projects, homework assignments from the text, and class participation.

Students learn to communicate with the instructor, TA, and other students using e-mail and a listserver for the course. In this manner, questions are answered very quickly, and new ideas can be easily exchanged. As a first assignment, all students created homepages which were embellished as the course proceeded. These enabled students to learn something about their classmates, and their team members. These webpages can be viewed at: HTTP://www.pitt.edu/-pittie/IEl021.

The course has been offered twice (40 students each time), with the following topics covered in approximately the order given in Figure 1. Felder's[10] exercise in determining learning styles is used to introduce the student to the different ways members in the class prefer to learn. The resultant data, with names disguised, is used by the students to develop a heuristic for dividing the class into teams. The class then votes on the best heuristics, and these are used to determine team assignments for the remainder of the course. Teams are changed at least four times. Several exercises from the Arizona State material[11], including a jig-saw exercise are used as part of the team building unit. Students are taught how to resolve conflicts that arise in the team exercises.

As noted, we have extensively adapted a number of Karl Smith's techniques [12], including the following for team work assignments:

. TASK: Solve the assigned problem correctly.
. COOPERATIVE LEARNING: One set of answers from the group, everyone has to agree, everyone has to be able to explain the strategies used to solve each problem.
. EXPECTED CRITERIA FOR SUCCESS: Everyone must be able to explain the strategies used to solve each problem.
. INDIVIDUAL ACCOUNTABILITY: One member from your group will be randomly chosen to explain a) the answer and b) how to solve each problem.
. EXPECTED BEHAVIORS: Active participating, checking, encouraging and elaborating by all members.
. INTERGROUP COOPERATION: Whenever it is helpful, check procedures, answers and strategies with another group.

Figure 1: Syllabus for IE 1021: Modeling With Computer Applications

1. Overview of course; active learning and learning styles; Richard Felder's quick and dirty type classification; communication by e-mail.
2. Introduction to the World Wide Web - HTML and "Home Pages"
3. Working in Teams; team building skills; notes from Arizona State University.
4. Introduction to modeling; heuristics and algorithms.
5. Mathematical Modeling - EOQ model; dimensional analysis. .Modeling Processes; sensitivity analysis.
6. Introduction to TQM - seven basic techniques; seven new techniques.
7. Time dependent models; rate models; renal dialysis problem.
8. Rate Models H - Predicting the spread of a disease.
9. Decision making under risk; probability and stochastic modeling.
10. Introduction to project planning and scheduling; discovering the shortest path algorithm, cpm, minimal spanning tree.
11. Introduction to linear programming.
12. Introduction to Engineering Ethics 1. Notes from Pinkus, Shuman, Hummon and Wolfe; ethical framework.
13. Working as a design team. Delta Design Project (A Habitat for the Deltoids).
14. Deltoid Design Competition; evaluating alternative de signs (cost, schedule, design criteria, and safety).

While only team grades are given, each team member is required to provide both an initial estimate and a final accounting of the amount of time he/she spent on the assignment (individually and with the team). Assignments have included developing a model for renal dialysis; designing a playground; improving the quality of student life; writing a program that simulates the game of Jai-alai (students had to first be taught the rules of the game through an in-class exercise involving betting Hershey's kisses on their favorite team); and evaluating different policies for reducing the spread of AIDS in Pennsylvania. We also successfully utilized the Delta Design Game developed by Bucciarelli at MIT.[13]

We believe much of engineering involves trade-offs between, cost, schedule and risk. This provides an opportunity to explore engineering ethics. We provide the student with our framework for resolving ethical dilemmas and work through two engineering ethics cases, including one on the Challenger which we have developed [14]. We want our students to appreciate that risk always exists, and it can easily be compromised to satisfy cost and schedule constraints.

As is true for all four courses, the instructors make a special point of learning the students names. This is done by taking their pictures the first day of class and then studying the pictures. TAs are selected for their interpersonal skills in addition to their technical capabilities.

Student Reaction to the Course

Students are very positive about the active learning format, teamwork and group projects, class participation and discussion, use of e-mail, engineering ethics, Delta Design and AIDS projects. They area little less ' enthusiastic about the programming assignments, and the TQM material. They least like the text book, and keeping a log book (which was dropped the second year). Not surprisingly, there have been complaints about the intentionally vague assignments, and a few students did not like to participate in a team experience. The vast majority of the class liked the idea of not having exams.

When asked what they learned from the course, the large majority indicated "teamwork/how to work effectively in teams," followed by new ways to solve problems, and insight into the thinking process. Others cited that they learned social/communications skills, how to delegate time, the importance of attending class, how to be productive, and how to develop heuristics.

Operations Design, Planning and Work Measurement

Traditionally this course and Introduction to Human Factors followed primarily a lecture format with examinations being the major tool for student evaluation. Although this format enabled a large amount of material to be covered, the instructor did not feel that the students were integrating the concepts they were learning into their understanding of engineering. Over the past four years, the instructional method for the two courses and the student assessment format have changed. Now students no longer sit passively receiving and recording information. Rather, the y take a substantial y more active role in their own learning processes.

In both this course and Human Factors, the students work on projects in teams. The concept of working in teams is reintroduced through additional classroom exercises which build upon the material covered in the previous course. This better prepares students for the types of problems they may encounter throughout the semester. In the sophomore level Introduction to Engineering course, the teams must apply each of the analysis tools (e.g. flow charting, motion analysis, work sampling) they learn to the same real world process. See Figure 2 for the course syllabus. The text for the course is Aft's *Productivity Measurement and Improvement*[15]. There are several lab assignments in which the tools must be applied to problems. In addition, there are three mandatory plant trips. Here the entire class observes industrial engineering in practice. The grade is based upon two examinations; a term-long team project; labs, homework assignments, and case studies; and class participation.

The goal of team project is to analyze a process using the analytical tools learned in class. The team must submit three written reports and make three oral presentations over the 14 week term. The first report covers data collection, flow charting, and motion analysis. The team makes a five minute presentation with appropriate overheads and handouts. The second report requires a time study and MOST analysis. The team must prepare a poster and five minute presentation. The third report requires work sampling and recommendations to improve the process based on the findings from all five analyses. An explicit discussion of each type of analysis is required. The team must prepare a ten minute presentation.

Figure 2: Syllabus for Operations Design, Planning and Work Measurement

1. Overview of Industrial Engineering
2. Case Study Analysis
3. Teamwork
4. Production Processes
5. Graphical Analysis Tools
6. Methods Improvement
7. Time Study
8. Predetermined Time Systems
9. MOST
10. Work Physiology and Ergonomics
11. Work Environments
12. Work Sampling
13. Productivity Improvement
14. Labor Unions

It should be noted that the poster session is a new experience for the students; hence, this assignment also introduces 'with-a-valuable-new communication tool,

— By the end of the semester students are able to evaluate each of the analysis tools with respect to the problem at hand in order to determine when each tool is most useful. In addition, they have learned how difficult it is to use tools (that are easily explained in a textbook) in a real world situation. Finally, the teams must produce three written reports and two oral reports on their work.

As with the other courses, material in each class is presented in a way to promote active student learning. For each new concept introduced, some interactive tool is used to motivate the topic or reinforce the main principles for the students. The tools used for this course and the following one include:

- Small group discussions - active application of tool
- Case studies - experiential learning
- Concept maps[16] - understanding connections
- Discussion - application of principles to design

The use of these methods reduces the amount of time available for lectures and it means that fewer topics may be covered in a semester, but the student response to this approach has been positive. Further, we believe that long-term learning is enhanced.

Student Evaluation

The students were asked to evaluate the teaching methods used in the course. Specifically, the instructor asked: -

I tried to present less material in lecture and have the class participate in exercises to reinforce what we were studying. What are your reactions?

While a few students responded: "I'd rather have the material," the majority of the students responded:

- Class participation is the best way to learn! The material stuck in my mind.
- This is effective, it keeps the class interested in the topic.
- I think this is always a good idea.
- Exercises helped in the reinforcement and also allowed for needed breaks in the lecture.
- I think that it was a success. The best way to learn is by doing something or actually seeing it done.
- Good idea. It keeps attention better. You also learn more by doing.
- I thought the class exercises were a good practice. Any material can be memorized but not a lot can be put into practice. It was good for the types of exam questions you gave as well.
- I thought that was very effective b/c I learned more from participation in exercises than from lecture notes.

HUMAN FACTORS ENGINEERING

Human factors is the science of fitting the environment, tasks or product design to the human. The design of most tools, machines, computer systems and work environments should include considerations of human capabilities and limitations. In this junior level course, students work in teams to redesign an existing product using human factors principles to consider human abilities, characteristics and motivations. Students must use the appropriate human factors analysis tools, and justify their suggested changes from the literature. They write an extensive paper describing their analysis and present their results orally two times during the semester. Concepts discussed in class are-utilized to perform several experiments. (See Figure 3.)

T-he-Course grade is based on two exams, five lab reports, a team project and a student led class. In the labs, students work with a partner for both data collection and report writing. They rotate partners after each lab assignment. Both partners are expected to have equal input during the lab and write-up process. Students work in teams of three or four for the term project. Each student evaluates both his/her individual participation in the project and that of each member of the team halfway through the term and at the end of the term. The course uses the text by Sanders and McCormick, *Human Factors in Engineering and Design*[1] 7. Assigned outside readings are made available in the library.

The most recent time the course was offered, instead of a product redesign, students developed a HyperCard Stack as the term project. Students then did the product redesigns as a laboratory exercise.

Figure 3: Syllabus for Human Factors Engineering

1. Introduction to Human Factors
2. Information Input and Processing
3. Visual Displays - Static and Dynamic
4. Motor Skills
5. Human Control of Systems
6. Controls/Hand Tools
7. Applied Anthropometry
8. Environmental Conditions
9. Illumination
10. Human Error

The students worked in teams to create a HyperCard stack of the main topics covered in the course. The HyperCard stack is simply an extension of concept maps in a computer environment that can allow multiple connections. The main purpose of this project was to have the students learn about the rich and varied nature of the connections among the various topics in industrial engineering. Class discussions then reinforced the idea that the concepts they learn in the human factors class are interrelated with concepts they learn in their other courses.

Since one of the best ways to learn is to actually teach, each project team must also teach a class session as part of the course. The team must select a topic to teach to the class, develop a lesson plan and conduct a class. The lesson plan must include the objectives of the class; a list of content the team expects the students to learn, and a copy of the overheads to be used. Because the course emphasizes active learning, the lesson plan must include an interactive activity for the class that either motivates or reinforces one or more concepts. These interactive activities might be to conduct a simple experiment and data analysis; a survey or preference elicitation; use small groups to critique a product, brainstorm the problems about a process, or design a task; a hands-on assembly of some product; or drawing a concept map. Also to be included in the lesson plan are four or five possible exam questions about the material and documentation of the literature search.

The student led class required the instructor to work closely with each team to help develop ideas for effective-activities and class presentations. (In some cases it probably took longer to work with students on these presentations than it would have taken for the instructor to prepare the information for herself.) However, as noted below, the students generally felt that this was a very valuable learning experience.

Student Evaluations

At the end of the semester, the instructor asked the students: *"What did you learn from doing the student led class?"* Responses included:

- They were a great assignment. More than the content, they taught team building and group dynamics.

I learned how to be more comfortable speaking in front of groups and how to weed out any unnecessary information.

- Since you know the material, you understood it better because you were forced to study it. Great way of changing monotony.
- Learned the subject well and how hard it is to keep a class's attention.
- I got a start in learning how to pull the most important ideas from a breadth of information
- Had to narrow information into just important stuff.
- Provided experience in presentations, and experience in working in a group to develop a presentation; found this very useful.
- The trade-off between quantity of information presented and the interest paid by the public.
- It is harder to prepare a lecture than it appears.

TOTAL QUALITY MANAGEMENT

This course is designed to expose students to the various TQM philosophies, to provide them with an understanding of the history and theoretical concepts underlying quality control, and to teach the modern techniques that are currently in use. The overall goal is to enable the students to be able to design a unique TQM program for a company or agency. Topics covered in the course are shown in Figure 4. Students are assigned to teams at the beginning of the course, and remain with those teams throughout the course.

Figure 4: Total Quality Management

1. Introduction to Quality and Paradigms
2. Mission and Vision
3. The Philosophies of Deming, Crosby and Juran
4. Other Philosophies of Quality
5. Kaizen
6. The Seven Basic Tools
7. *The Goal*
8. Benchmarking
9. Quality Function Deployment
10. Re-engineering
11. Malcolm Baldridge Award
12. ISO 9000
13. The Statistics of Control
14. Acceptance Sampling
15. Single Sampling Plans
16. Double and Sequential Plans
17, X and R Charts
18. Rational Sampling
19. Interpretation of Control Charts
20. Process Capability
21. Process Improvement through Charts
22. Cusum Control Charts
23. Introduction to Taguchi Methods
24. Six Sigma Quality
25. *The 7 Habits of Successful People*

The topics covered can be divided into three broad categories - philosophies, tools, and organizers. The philosophies especially require substantial reading assignments. To make the reading more palatable and to assure discussion, several methods are used. There is a text for the course, *Creating Quality*[18] (Kolarik), which is very comprehensive and serves as a constant reference to the class. Other reading material, in particular, the philosophies of Deming, Juran, Crosby, etc., is learned by having each team do a comprehensive book report and class presentation on an assigned philosophy. Each team must also do a group book report on *The Goal*[19]. Every team member must be prepared to discuss this book in class. The in-class discussion revolves around questions by the instructor to randomly selected students. Everyone in the class is encouraged to participate and argue points in the book or comment on its meaning. Finally, two books, *Reengineering the Corporation*[20] (Hammer and Champy) and *The 7 Habits of Highly Effective People*[21] *(Covey)* are assigned in the form of audio cassettes with the expectation that each student will be prepared for a class discussion on each book.

Most of the tools presented in the course are accompanied by in-class exercises. This enables students to work in teams to better learn such techniques as brainstorming, benchmarking, affinity diagrams, etc. By actually applying the method, students not only learn the technique extremely well, but also are more likely to ask questions and engage in meaningful discussions. Each team also must complete a TQM statistical design project which involves bringing a production system under control. Teams are given data sets of processes that may or may not be in control. They have to determine the status of the process. They are permitted to ask the teaching assistant questions about the process. They are then permitted to get more data, but data is not "free." Teams are given a cache of money to "purchase" data. More data costs more money. The students submit results and are given an opportunity to buy additional data over a period of three weeks. The final result is judged in terms of the money spent, correctness of the result, and presentation to the class.

The course grade is based on two exams, the book report, design project, homework and class participation. Unlike the first three courses, a number of the students in the course are from other engineering departments. Consequently, they have not been as extensively exposed to teamwork at the beginning of the course as have the industrial engineering students.

Student Comments

Students were surveyed concerning the teamwork aspects of the course. Almost 90% liked working in teams. However, only 58% found the assigned team projects interesting. This is most likely because a number of students did not like having to do a team book report. Further, only half of the students felt that everyone was participating equally in the team assignments. Yet, only 22% wanted to remove certain members from their team. The primary reason for not participating fully was due to attendance problems caused by tight scheduling, heavy course loads, and commuting students. A number of students cited shyness as the reason for limited participation. Further, only 19% felt that other team members were negatively impacting their grade. Almost 90% of the students felt that the team was either functioning better at the midpoint of the term than at the beginning, or had been functioning quite effectively at the start of the class.

Students major concerns were directed toward the team assignments. There was a strong desire to have team assignments that could be more easily subdivided into parts. Students also wanted smaller groups (i.e., three persons) rather than the five person teams used in the class. Finally, they pointed out limitations with the classroom facilities and expressed a desire to use more class time for working on the team projects.

CONCLUSIONS

All four courses are well received by the students. The switch from a primary lecture format to active. learning requires the instructor to spend considerable time planning how each class period will be conducted. This planning of activities may take longer than preparing a lecture, and is one of the reasons that some faculty are reluctant to adopt this method of instruction. Since class participation is considered in grading each of the courses, it is the instructor's and TA's responsibility to learn the names of all students as rapidly as possible. This is primarily accomplished by photographing the students during the first class period, and then studying the pictures until the names of all students are known. E-mail is also used as a major way of interacting with students.

One major problem persists - classrooms designed for lecturing are not well suited for active learning, particularly when team activities are a major part of the class period. We now recognize that we need to equip classrooms with tables that each can accommodate a team of four or five students and their material. A second problem involves those few students who do not like teamwork, or prefer to work alone. Our experience indicates that less than 10% of-the class may fall into this category, but these individuals can cause problems for their team. A related problem occurs in the TQM course. Here, students from other departments have not been exposed to teamwork concepts, and must be brought up to the same level as their industrial engineering counterparts. This must be accomplished without boring the IE students who, by this point in their education, are very familiar with team concepts. Finally, the international students in the class may present a problem for their team if their written English language skills are weak. In this case, team members maybe unwilling to let them help write the report, and they run the risk of being relegated to a secondary role in the team. Also, if they do not feel comfortable with their oral communication skills, their participation in the team may suffer. It is important that the instructor continually remind students about the importance of being able to work in a team, and develop the ability to respect their fellow team members.

REFERENCES

[1] Felder, R.M. and L.K. Silverman, "Learning and Teaching Styles in Engineering Education," *Engineering Education, 78(7),* pp. 674-681, 1988. Also see Felder, R.M and R. Brent, *Cooperative Learning in Technical Courses: -Procedures, Pitfalls and Payoffs,* ERIC Document Reproduction Services, in press.

[2] Smith, K. A., "Cooperative Learning: Effective Teamwork for Engineering Classrooms," *IEEE Education Society Newsletter,* April 1995, pp. 1-6.

[3] Evans, D., *Team Training Workbook and Facilitator's Guide, Arizona State University, 1994; see* also Student Teaming and Design, USE-9156157.

[4] Morrow, R. M., "Issues Facing Engineering Education", *Journal of Engineering Education, 83(1)* Jan. 1994, pp. 15--18.

[5] Morrow, R. M., ibid.

[b] Otala, L., "Studying for the Future: Lifelong Learning in Europe, the US and Japan", *ASEE Prism,* Oct. 1993, pp. 23-27.

[7] Black, K. M., "An Industry View of Engineering Education", *Journal of Engineering Education, 83(1),* Jan 1994, pp. 26-28.

[8] Monteith, L.K. "Engineering Education - A Century of Opportunity", *Journal of Engineering Education, 83(1)* Jan. 1994, pp. 22-25.

[9] Starfield, A. M., K.A. Smith, and A. L. Blelock *How to Model It - Problem Solving for the Computer Age,* Minneapolis: Burgess Publishing, 1994.

10 Felder, R.M. and L.K. Silverman, op. sit.

[11] Evans, D., op. sit.

[12] Smith, K. A., "What Works in University Teaching," Active and Cooperative Learning Workshop, University of Pittsburgh, April 1, 1995.

[13] Bucciarelli, L., *Delta Design Exercise,* Delta Design, 60 Kliburn Rd., Belmont, MA 02 178; see also "Design as Negotiation," *ASEE Prism,* Jan. 1995, p. 18.

14 Pinkus, RL, Shuman, LJ, Hummon, NG, and Wolfe H: *The Ethical Behavior of Engineers: An Analysis of the Space Shuttle Program,* To be published by Cambridge University Press, 1996.

[15] Aft, L. S., *Productivity Measurement and Improvement,* Englewood Cliffs, 1992.

[16] A concept map is a node and arc diagram that represents a person's understanding of the relationships among concepts. Concept maps can help student make and understand connections among concepts. They can be an effective tool to elicit a student's understanding of a topic both before and after instruction.

[17] Saunders, M.S. and E. J. McCormick, *Human Factors in Engineering and Design,* McGraw-Hill, Inc., New York, 1993.

[18] Kolarik, W.J., *Creating quality Concepts, Systems, Strategies and Tools,* McGraw-Hill, Inc., New York, ‘ 1995.
[19] Goldratt, E.M. and Cox, J. *The Goal: A Process of Ongoing Improvement,* North River Press, Inc., Croton-on-Hudson, 1992.
20 Hammer, M, And Champy, J., *Reengineering the Corporation,* Harper-Business, New York, 1993.
21 Covey, S. R., *The 7 Habits of Highly Effective People,* Simon and Schuster, Inc., New York, 1989.

Biographical Information

Larry Shuman is Associate Dean for Academic Affairs, School of Engineering, University of Pittsburgh, and Professor of Industrial Engineering. His primary areas of interest are the application of operations research to health delivery systems, improving the engineering educational experience and the ethical behavior of engineers. He holds a Ph.D. in Operations Research from the Johns Hopkins University, and a B.S. in Electrical Engineering from the University of Cincinnati. He is a member of IIE, ASEE, INFORMS, IEEE, and AHA.

Cynthia J. Atman is an Assistant Professor of Industrial Engineering at the University of Pittsburgh. She received her B.S. in Industrial Engineering from West Virginia University, her M.S. in Industrial Engineering from Ohio State University, and her Ph.D. in Engineering and Public Policy from Carnegie Mellon University. She is the recipient of a National Science Foundation Young Investigator award to pursue her research in engineering education. She is a member of IIE, ASEE, HFS, AERA, NASTS, SRA and SWE.

Harvey ‘Wolfe is Chairman and Professor, Department of Industrial Engineering, University of Pittsburgh. He holds the B.E.S. (Industrial Engineering), M.S.E. (Operations Research) and Ph.D. (Operations Research) degrees, all from the Johns Hopkins University. He has conducted a number of major, interdisciplinary research studies to investigate the planning, monitoring, evaluation, community decision making and impediments to development of health care delivery systems. He is an IIE fellow and a member of ASEE, INFORMS, and AHA.