Teaching Creative Thinking and
TRANSITIONING STUDENTS TO THE WORKPLACE
in an Academic Setting

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During their undergraduate careers, students are given the opportunity to learn the fundamentals of chemical engineering and to begin to develop their closed-ended problem-solving skills, writing abilities, and oral presentation skills. Many problems facing students in classroom settings are limited in scope, however—an issue magnified by the dramatic shift and broadening of scope seen in the job expectations of chemical engineers over the past 30 years.[1-3] This shift has required chemical engineers to be integrated with a large number of different fields such as materials science, electrical engineering, biology, chemistry, physics, and business. These new frontiers require chemical engineers to solve problems using creative, unique means.

To meet these challenges, employers are placing a greater importance on hiring graduates with developed skills in critical thinking, creative thinking, and problem solving. Consequently, universities need to focus on ways to better develop these skills in students during their undergraduate and graduate careers.[4,5] Engineering students have become increasingly aware of this fact and in a recent study, a large majority indicated that they would like to take a course in critical thinking, creativity, and creative problem solving.[5] In addition to developing creative thinking skills, students will also have to develop a new set of interpersonal and intrapersonal skills as they transition into a work environment. Students absorb a vast skill set from work completed both in academia—whether inside of the classroom or as a member of a student group—and from any external experiences such as an internship or a co-op. However, these experiences typically do not expose students to a litany of issues that they will face once they enter the workforce. Typical questions that an employed young engineer can face include: How should I invest my money? What issues will I face now that my work has sent me to a foreign country? How do I negotiate and when is it acceptable to negotiate? What do I need to know if I want to create my own company? Although an academic course is unable to address all of these issues in an in-depth manner, exposure to these and other non-technical issues is of great benefit and interest to students.

Recognizing these deficiencies in student training, several different solutions have been developed. Several books have


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TABLE 1
Course Topics By Week for the Fall 2012 Semester

Week	Topic
1	Introduction, Developing a Right Frame of Mind, Steven Covey's 7 Habits, 7 Actions for a Successful Career, Paradigm Pioneers
2	Developing a Survey, Gantt/Deployment Chart, Creativity Skills, Knowing the Customer
3	Introduction to Problem Definition, Structured Critical Reasoning
4	Problem Definition: More on Structured Critical Reasoning, Duncker Diagram, Statement–Restatement Technique
5	Problem Definition: Kepner-Tregoe (Problem Analysis, Situation Appraisal)
6	Kepner-Tregoe (Decision Analysis, Potential Problem Analysis)
7	Midterm Project Presentations (Status Report of Term Project with Local Businesses)
8	Time Management, Troubleshooting, TRIZ
9	Implementation, Evaluation, Negotiation Skills
10	Negotiation Skills Exercise
11	Executive Book Summary Presentations
12	Ethics, Financial Planning for a Young Engineer
13	Having a Vision, Entrepreneurship
14	Final Project Presentations

been written to make engineers more cognizant of these necessary "soft skills."[6-9] These books are quite varied in the qualifications of their authors (*e.g.*, business people, entrepreneurs, practicing engineers, engineers in academia), topics covered in the books (critical thinking, project management, ethics, presentation skills, engineering design, marketing, etc.), and their intended audience (underclassmen engineers, upperclassmen engineers, engineers at their first jobs, etc.). Research has been conducted exploring how these skills can be integrated into the curriculum, whether at the freshman level or throughout the curriculum.[10-12] The most thorough of these publications is a 25-year study conducted at McMaster in which problem solving was developed throughout the chemical engineering curriculum.[10] Colleges have developed a number of programs to increase student exposure to these crucial skills needed when they enter the workforce or graduate school. Some of these programs include the Professional Practice Skills Program at Rose-Hulman Institute of Technology, the aforementioned McMaster Problem Solving Program, and the Dartmouth Project for Teaching Engineering Problem Solving at Dartmouth College.

At the University of Michigan, Ann Arbor, a 3-credit-hour course, Engineering 405, entitled Problem Solving, Troubleshooting, and Making the Transition to the Workplace, was created. The course is based on the text *Strategies for Creative Problem Solving* by Fogler, LeBlanc, and Rizzo.[6] The basis for the textbook came from a National Science Foundation grant that looked at and analyzed problem solving in industry. The course was first offered in the Fall semester of 2006 and has been offered on an annual basis since, except for 2009. Because of sufficient cross-departmental advertising, the course has annually enrolled approximately an equal amount of chemical engineers and non-chemical engineers. These non-ChE students have primarily been enrolled in industrial engineering, but students from materials science, aerospace engineering, electrical engineering, and mechanical engineering have also enrolled in the course. Enrollment for the class is generally in between 20 and 30 with an even mix of juniors and seniors.

COURSE STRUCTURE

The course meets twice a week for an hour and a half. The main components of the course are lectures/discussion, in-class problems, homework problems, and a term project. The three major goals of the course are to: (1) develop and enhance critical thinking and creative problem-solving skills, (2) prepare students for the workplace, and (3) be able to apply the skills learned in class to a real-world situation. A brief syllabus from the Fall 2012 semester, noting the topics of the course, is shown in Table 1. It should be noted that although modifications have been made to the syllabus based on speaker availability and a greater focus on structured critical reasoning, the majority of the course has remained unchanged through the years. The following elements are featured.

Problem Solving Lectures: Creative problem skills were introduced and developed using the problem-solving heuristic outlined in Fogler, LeBlanc, and Rizzo.[6] *The heuristic will be described in more detail later.*

Guest Lectures: The lectures dedicated to specific topics regarding the workplace are primarily given by members of the industrial sector. Their lectures have addressed such topics as how to prepare a survey, entrepreneurship, knowing the customer, engineering ethics, financial planning, cross-cultural communication, and gender issues in engineering. Although many of the guest lecturers have a background in chemical engineering, they represent a cross-section in terms of industrial experience, type of company, size of company, and roles within the company. The lectures are designed for an intended audience of general engineers. As needed, some of these lectures involve exercises that the students have to complete either before or after the lecture. For example, the lecture on entrepreneurship required the students to develop a 30-second elevator pitch to a job recruiter and then present it in front of the class.

Group Problems: (50% of the overall course grade) Students complete an in-class problem at the end of every lecture to immediately apply the tools learned in the lecture. Out of class problem sets are assigned to further reinforce the concepts discussed in class. The problems are primarily completed in teams of 3 or 4. These teams work together *throughout the semester and are assigned based on final project preference and the criteria that no group could contain more than two students from the same major.*

<u>Term Project:</u> (50% of the overall course grade) Teams consisting of 3 or 4 students are given the opportunity to apply the problem-solving heuristic to a particular business or organization through the course project. Each team is asked to carry out the analysis shown in Table 2 for their business.

The term project is the major focus of the course and requires interacting with a local business or organization (hereafter referred to as the client) to find the spoken and unspoken problems, generate a number of solutions to each problem identified, weigh the pros and cons of each solution, pick the best solution for each problem, and prepare an implementation plan. Table 3 provides a list of clients that have participated in the class since the course's inception. The projects have represented a mixture of on-campus groups, national chain companies, local chain companies, and small businesses. The clients allowed students to interview and conduct surveys with employees, and in some cases customers (or students). (Because the surveys are a major source of information gathering for the projects, a guest lecture by a professor at the Ross School of Business at Michigan is given to introduce students to developing and administering a survey.) With few exceptions (generally the larger chain companies), the clients are most willing to assist the students in obtaining the information they require. This accessibility allows the students to fully explore the problems they find without repercussions from upper management.

The major deliverables for the project are a midterm status update, a final presentation, and a final report. The final presentation and report are provided to the client. The status report is used to (1) check on the progress of the groups to ensure they were on track to finish the project by the end of semester, and (2) have the students assess the potential problems they might face when finishing their project and determine appropriate contingency plans. The final presentation (25 minutes in length) highlights the key findings, and most importantly, demonstrates how the techniques acquired in the class were used to analyze and solve the clients' problems. The presentation is followed by a 20-minute question-and-answer session. In the first couple of years these questions were asked by the instructional staff and students. Over time, however, guest panelists were included—including some of the managers of the respective projects, with a wide breadth of industrial experience. Incorporating the guest panelists greatly enhanced the quality of the Q&A portion of the presentation with their fresh, less-academic perspectives.

PROBLEM-SOLVING HEURISTIC

The problem-solving heuristic that the students use can be broken down into five separate sections: problem definition, solution generation, deciding a course of action, solution implementation, and solution evaluation. Figure 1 shows a schematic of the heuristic.

TABLE 2
Objectives for Term Project

1	Define or uncover a number of problems, both spoken and unspoken.
2	Generate a variety of solutions for each problem.
3	Carry out an analysis to choose the best solution for each problem.
4	Carry out a potential problem analysis for each solution generated.
5	Propose an implementation plan.
6	Evaluate each step of the project.

TABLE 3
Clients Involved in Term Projects

Ace Barnes Hardware
Bear Claw Coffee
Bella Vino (upscale beer/wine/grocery store)
Betty Brigade (concierge services/event planning)
Espresso Royale Coffee
Gross Electric (industrial/commercial lighting)
Menlo Innovations (custom software design and development)
Panera Bread
Qdoba
University of Michigan Chemical Engineering Department
University of Michigan Housing
Zoup!

PROBLEM DEFINITION

As noted earlier, the development of the book used for the course arose from a grant from the National Science Foundation to learn how employees in government, industry, and universities solved problems. When asked to define the greatest challenge faced in solving problems, a majority said the

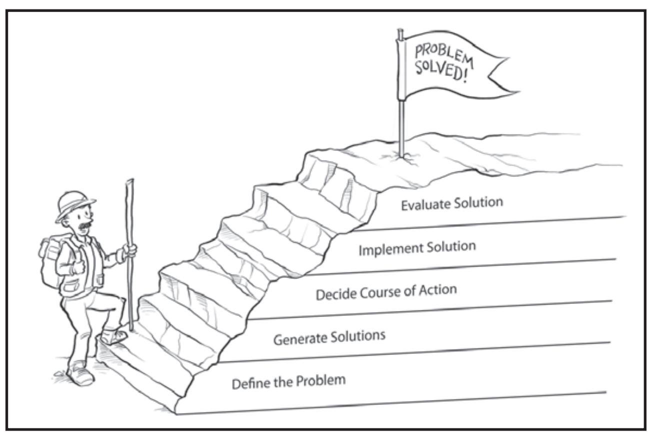

Figure 1. *Schematic of the problem solving heuristic.[6] Reprinted with permission from Reference 6.*

TABLE 4 **First Steps in Problem Definition**[6]	
1	Collect and analyze the appropriate data.
2	Talk with people who are familiar with the problem.
3	View the problem first-hand (if possible).
4	Confirm all findings and continue to gather information.

largest issue was improper problem definition, which often led to solutions that were expensive and/or didn't solve the actual problem. From visiting a variety of chemical and oil companies, a number of examples were collected where the perceived problem was defined and a solution attempted.[6] The major issue faced when solving a perceived problem (or symptoms of a problem) is that it is often incorrectly or too narrowly defined, artificially reducing the number of possible solutions and potentially eliminating the most viable solutions. For example, the Bureau of Engraving and Printing in 1990 attempted to remedy the smearing of ink on the new paper money being developed for circulation.[6] The initial problem statement was "*Develop a program to find better printing inks*." After spending significant time and money to research programs to develop a program to find better printing inks, the Bureau realized that the real problem was not with the inks but the new printing machines, which were applying insufficient pressure onto the new type of paper to allow for the ink to settle inside the paper's fibers. If the initial problem were more broadly defined as *"Find out why the ink was smearing,"* then improving the printing machines would have been available in the initial solution generation and the money used to find better printing inks could have been more effectively utilized.

To help the students define the real problem, a number of techniques were presented and used. The first steps in understanding and defining the real problem involve obtaining information and are presented in Table 4.

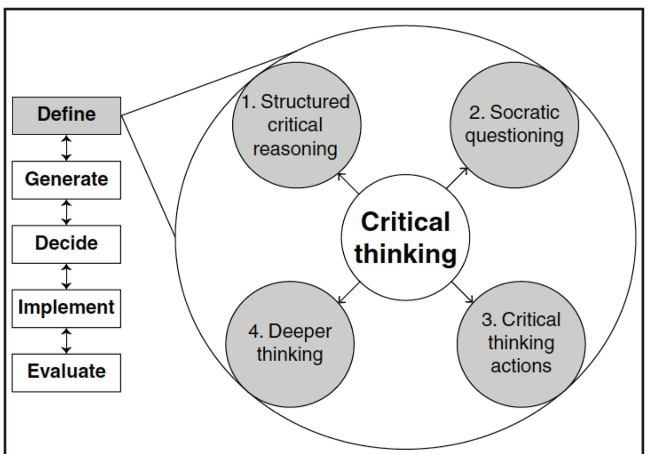

Figure 2. *Problem Definition Techniques.*[6] *Reprinted with permission from Reference 6.*

TABLE 5
Structured Critical Reasoning[6, 13]

Step	Action
1	Identify all of the conclusions.
2	Look for the evidence that supports each conclusion.
3	List all major assumptions.
4	Evaluate all of the assumptions and evidence.
5	Identify one of the 11 fallacies in logic (*e.g.*, Citing Questionable Authority, False Dilemma, Causal Oversimplification).

During this process, it is crucial to ask critical-thinking questions that can uncover the real issues that are being faced. Once the information has been gathered, an initial problem can be developed and then refined using a number of techniques shown in Figure 2 and discussed below.

1. *<u>Critical thinking</u> utilizes the structured critical reasoning algorithm*[13] *or Socratic Questioning to ferret out the real problem. Developing critical-thinking skills and proper problem definition are at the heart of successful problem solving and therefore have the most lectures devoted to them in comparison to all other topics in the course. Students are rigorously exposed to the Structured Critical Reasoning algorithm shown in Table 5. A number of in-class and take-home exercises reinforce their understanding of the material so that it can be optimally utilized for the term project. As an example, students were asked to apply Table 5 to an editorial in a newspaper such as* The New York Times, The Wall Street Journal, *or* The Guardian.
2. *<u>Socratic questioning</u> is the crux of critical thinking and is further reinforced in the course by showing how its usage can uncover the real problem from the perceived problem.*[6] *The six types of questions include a) about the question, b) for clarification, c) that probe assumptions, d) that probe reasons and evidence, e) that probe viewpoints and perspective, and f) that probe implications and consequences.*
3. *<u>The Duncker diagram</u> can be used to broaden a problem statement by determining perfectly viable solutions to the problem that may not satisfy the currently defined desired state.*[14] *The unique feature of the Duncker diagram is that it suggests a way to make it okay to NOT solve the problem—which is then used to help define the real problem instead of the perceived problem.*
4. *<u>The statement-restatement technique</u> helps refine the original problem statement by rephrasing the problem statement to enable the most accurate representation of the problem to be reached.*
5. *<u>Kepner-Tregoe (K-T) problem analysis</u> uses the four dimensions of a problem: what, where, when, and extent, and uses critical thinking to determine distinctions between what the problem is and what the problem is not.*[15]

SOLUTION GENERATION

Once the proper problem statement has been developed, the next step is to come up with a number of potential solutions to the problem. Even if the problem is accurately defined, many solutions may not be considered or even thought of because of the mental blocks that people have developed while generating potential solutions. Making students aware of these blocks—conceptual, perceptual, emotional, cultural, environmental, and intellectual—and exposing them to methods to overcome blocks, makes them more open to generating a wider range of solutions, no matter how improbable the solution may sound.[16,17] Students are then introduced to a broad set of solution-generation techniques that take advantage of a number of different thinking processes beyond the typical free association used in brainstorming. The use of Osborn's checklist (vertical thinking) allows students to add new ideas by doing such things as modifying, magnifying, and rearranging a particular part of a problem.[18] Techniques to promote out of the box and lateral thinking—such as random-stimulation words and using other people's views—are practical methods to generate ideas that may not have been obtained in simple brainstorming.[17] These and other lateral thinking techniques, such as futuring, analogy, cross-fertilization, and TRIZ (an acronym for a Russian term describing a problem-solving procedure that allows for evolution of technical systems by overcoming contradictions in the problem using minimal resources), help the students think out of the box to develop further ideas. For example, students are exposed to the 48×48 TRIZ contradiction matrix that allows for solutions to be developed by resolving apparent contradictions in a problem statement and its utility.[19] An actual case history regarding the modification of the Boeing 737-100 series airplane is discussed to show how a TRIZ analysis can be applied. In this example, Boeing decided to increase the number of passengers, requiring a corresponding increase in engine size. The increase in engine size resulted in the clearance on landing between the runway of the bottom of the cowling of the jet engine not being able to meet safety standards. A TRIZ analysis was used to solve this contradiction.

DECIDING A COURSE OF ACTION

Once the actual problems have been identified and many potential solutions for each problem have been developed, the next step is to determine which problems are most important and which solution is most viable. The students are introduced to the work of Kepner and Tregoe, who developed a systematic approach in assessing the most immediate or pressing problems and the most viable solutions.[15] The four components of Kepner-Tregoe are shown in Figure 3.

1.) *Situation Appraisal: Situation appraisal helps to decide which problem and process should be handled first and evaluates all the problems by three criteria: timing (the immediacy of the problem), trend (the evolution of the problem over time), and impact (the seriousness of the problem). This evaluation allows students to determine which problems are most important and should be addressed first. It also helps determine the next step in solving the problem: finding the root of the problem (problem analysis), deciding between potential solutions (decision analysis), and/or identifying potential problems that may arise from the chosen solution (potential problem analysis).*

2.) *Problem Analysis: Problem analysis was discussed earlier in the problem definition section.*

3.) *Decision Analysis: Decision analysis is a systematic approach used to determine which of a number of generated solutions best solves a problem. From their knowledge of the problem through the information-gathering process, the students are able to break the objectives that the solution needs to address into two categories: musts*

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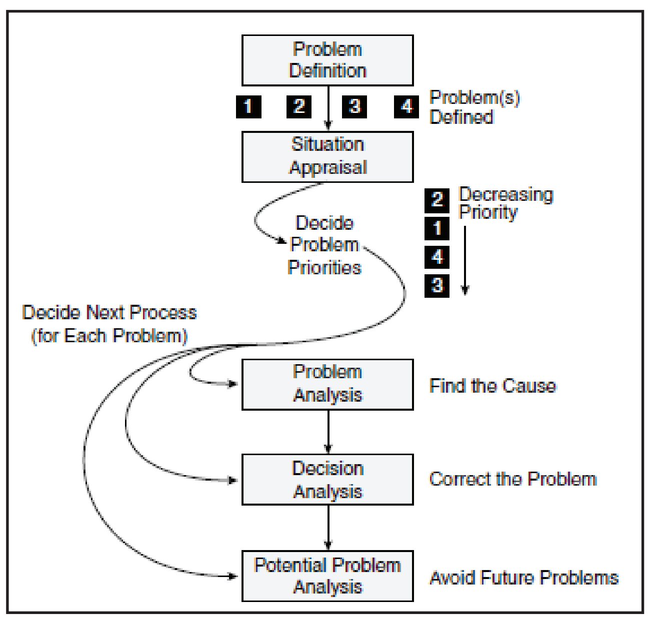

***Figure 3.** Components of Kepner-Tregoe Analysis.[6, 15] Reprinted with permission from Reference 6.*

and wants. Any solution that does not satisfy all of the musts is immediately rejected as an infeasible solution. The wants are valued and scored for each alternative solution to arrive at the best solution. Finally, adverse consequences of the solution are assessed and evaluated based on their importance and how well the solution satisfies them to reach a final decision.

4.) Potential Problem Analysis: A potential problem analysis is done to ensure the success of the solution by analyzing what could go wrong with the solution and how to handle it. This process is developed by brainstorming to identify the potential problems, finding their possible causes, determining a preventative action, and, finally, developing a contingency plan if any of the potential problems come to fruition.

IMPLEMENTING AND EVALUATING THE SOLUTION

Because of the time constraints of a semester-long course, it is infeasible to complete a thorough implementation and evaluation of the solutions since they are not fully developed until the end of the course. Some of the tools used for solution implementation, however, are discussed and used by students as guideposts for completing the project. The concepts of a Gantt chart, a deployment chart, and a budget are presented to allow the students to structure their course project, assuring that tasks were being completed and appropriately divided among the group members. Additionally, groups are asked to explain how they expected the solutions to their problems to be carried out and what follow-up procedures would need to be completed to evaluate the overall success of the solution.

For the scope of the work completed in the class, the evaluation step is utilized as a means to ensure that the group's proposed solutions make sense. The three major issues to assess in the evaluation stage are whether the solution (1) solves the problem completely, (2) prepares a path forward, (3) is safe, and (4) is ethical.[6] For the problems the students analyzed, safety and ethics were generally not of great significance for the solutions they provided. It is important, however, to make students aware of these issues when analyzing situations, particularly of engineering ethics—a topic generally not discussed in great detail in the chemical engineering curriculum. Table 6 shows how the heuristic was used for a term project completed in the course.

ADDITIONAL TOPICS

Book Summaries: The students are introduced to the monthly *Executive Book Summaries* and each group is asked to prepare a 20-minute presentation on one summary of their choice. The students are asked to inform their fellow classmates what the take-home points were from their particular summary that could be useful information in their future development as engineers. This series of books can serve as a resource upon graduation in a variety of job and management skills. Examples of books presented include *The Steve Jobs Way: Leadership for a New Generation* by Jay Elliot, *Persuasion IQ: The 10 Skills Needed to Get Exactly What You Want* by Kurt Mortensen, and *Working with Emotional Intelligence* by David Goldman.

Troubleshooting: Students are exposed to methodologies to enable them to handle technical problems, whether for a piece of equipment not working as expected or for a new installation not working as desired. The methodologies are a combination of the aforementioned Kepner-Tregoe analysis and other analyses including assessment of symptoms, understanding of fundamentals, reliability of data, and determination if a proposed answer fits the observations. Although some of these examples are rooted in chemical engineering unit operations, the problems are structured in such a way that they are approachable and solvable for students with a general engineering background.

STUDENT AND CLIENT FEEDBACK

The course has evolved in part based on input provided by the students at the end of the semester. Overall, the course has become such a valued and popular course that there was a significant wait list for the course in the Fall 2012 semester. The end-of-course survey (independent of the University of Michigan course evaluations) consists of two parts: (1) four questions asking students for their general thoughts on what they liked and disliked in the course, advice for future classes, and the most important things they learned in the course; and (2) four questions asking for what they learned in the areas of problem solving, completing their project, teamwork, and communication. The results from some of these questions can be found in Table 7.

LESSONS LEARNED

An interesting trend that has been seen is the divergent tastes of the students on course topics not directly related to the problem-solving heuristic. A particular topic of interest for some students was a topic other students believed should be eliminated from the course and vice versa. Therefore, offering a wide range of "soft skills" topics has been consistent through the development of the course, although topics evolve based on the availability of guest lecturers. Although only briefly discussed in the course lectures, the concepts of teamwork (particularly how to handle group conflicts, how to appropriately distribute the workload, and how to interact with fellow group members), time management, and communication skills came through as lessons the students gained by taking the course.

Anecdotally, the response from students and industry has been quite positive. Former students have returned to campus and have noted that the course was extremely beneficial in job interviews and is a specific elective upcoming students should take. Managers from the local businesses involved

TABLE 6
Usage of the Problem Solving Heuristic to Solve a Real-Life Problem

This group was asked to: "Determine the problems employees have at a bakery-café in Ann Arbor. Analyze the problems you uncovered and then generate and evaluate solutions for each problem. Finally, pick the best solution for each problem you identified."[6] (The information presented here represents only a portion of the work completed.)

Problem Definition	Information was gathered by interviewing the manager using-critical thinking questions and conducting employee surveys developed using brainstorming techniques and techniques learned in class (22 out of about 30 employees responded). The bakery-café was visited during dinnertime to observe both the employees and the customers. From this information, three major concerns were identified: (1) Bottlenecks occur because of insufficient staffing. (2) Co-workers do not take responsibility for their tasks. (3) Employees do not receive enough training for their tasks. Brainstorming techniques were utilized to develop the survey. The statement-restatement technique and Duncker diagram were used to ensure that the problem definitions were addressing the real problem.
Solution Generation	Both lateral thinking and vertical thinking were used to generate solutions. For example, for problem (3), ideas such as having practice runs before opening, employee testing, assigning fellow employees as trainers, and making work instructions present and in plain view at each workstation were all suggested.
Deciding a Course of Action	A K-T situation appraisal was done on the three problems to determine which problem was most important. Problem (2) was viewed to be the most pressing problem followed by (1) and (3). The group decided that they were able to evaluate and analyze all problems for their project.
	Problem (2) was further investigated by using a potential problem analysis. Solutions to handle this problem include a task checklist and rewarding employees for their work. The group realized that both initiatives could be implemented at the same time and made that recommendation.
	Problem (1) was further investigated using a decision analysis. Four solutions: hire more workers, purchase more equipment, transfer workers between shifts, and early shift preparation. Their analysis led them to the suggestion that purchasing additional equipment would be the most viable solution.
Implementation	The implementation of the results to Problem (2) will be carried out by creating laminated sheets with the appropriate tasks on them. If issues were to continue, employees would be required to initial the sheet when the job was completed, per the potential problem analysis. Another idea developed was the concept of a "check-out" employee who would make sure that all of an employee's tasks were completed before an employee could leave.
Evaluation	To determine employee satisfaction with the changes, short surveys or interviews could be conducted by the group (or a set of people not affiliated with the management). Most of the evaluation of this will be readily seen by managers on a day-to-day basis.

TABLE 7
Sample Responses From In-Class Student Feedback From Classes Over the Last Few Years

Q: *What advice would you give to next year's class?* The total in parentheses represents how many students noted this issue or something closely related (N=45)	"Start early with the project and set up regular times to meet with your group." (32)
	"Outside of class, think about situations or other classes you could apply the material: you'll surprise yourself." (18)
	"Go to class every day and pay attention and take notes. The real detriment will be to your personal experience if you don't." (17)
	"Take advantage of the guest lecturers and ask questions." (7)
	"Mention that you've taken a problem-solving class in any interviews you have and you'd be surprised how impressed people are when you can explain a Kepner-Tregoe decision analysis." (1)
Q: *What are the most important things you have learned from the course?* Students were asked to provide their top four choices. The total in parenthesis represents the number of students that had this topic in their top four.	Kepner-Tregoe Analysis (40)
	Critical and Creative Thinking (22)
	Teamwork (22)
	Financial Planning (15)
	Negotiation (14)
	Problem Definition (13)
	Communication Skills (8)
	Cultural Differences (4)

with the course have been impressed with the quality of the students' work in the program and have taken some of their ideas into account when making business improvements. One of the client managers wrote an unsolicited letter to the dean of Engineering saying how valuable she thought the course was. In some cases, however, the student groups did not feel that the clients responded to their needs during the term. Consequently, it is crucial that the instructor discusses (in advance of the beginning of the semester) with the client the need to allot 3 to 4 hours to the students during the semester for discussion and assistance.

Course material and summary notes from the course are available at: <http://www.umich.edu/scps/>.

CONCLUSIONS

A new course developed at the University of Michigan at Ann Arbor exposed upperclass undergraduates in engineering to a wide range of ideas to develop their creativity and their problem-solving abilities, plus a number of issues they will confront as they transition into the workplace. The use of real-world examples and a course project allowed students to directly apply the problem-solving heuristic discussed in lecture and recognize that these concepts are not solely academic and can be used in their daily lives. Feedback from the students indicated that in addition to learning the course curriculum, they developed their abilities in teamwork, time management, and communication skills—skills crucial to a professional engineer, but often underemphasized in academic settings.

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