2006-1150: INTRODUCTION TO ENGINEERING THROUGH REAL-WORLD CASE STUDIES

Chetan Sankar, Auburn University

P.K. Raju, Auburn University
Introduction to Engineering through Real-World Case Studies

Introduction

By the year 2020, the world population will approach 8 billion people, and much of that increase will be among groups that today are outside of developed nations\(^1\). The marketplace for engineering services will be worldwide, and jobs will move freely. Information sharing allowed by the Internet, broadband communication links, and high speed computers has the effect of tying cultures, knowledge, and economy together with possible positive as well as negative impacts on U.S.-based engineers. These contemporary challenges require a systems perspective and a growing need to pursue collaborations with multidisciplinary teams of technical experts. Important attributes for these teams include excellence in communication (with technical and public audiences), an ability to communicate using technology, and an understanding of the complexities associated with a global market and social context\(^2\).

In order to ensure that engineering students studying in any university in the US receive an appropriate and useful education, ABET a-k criteria have been created. This states that engineering programs must demonstrate that their graduates attain:

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(d) an ability to function on multi-disciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

This expectation is based on elaborate research carried out by ABET together with a number of commercial organizations in order to identify the kind of engineers that are needed for the 21st century. These expectations are further supported by a study performed by researchers at Auburn University. This study asked managers in 23 companies about the skills, knowledge, and abilities that are valued by them in addition to the more traditional skills learned in the major discipline. Table 1 shows the results of this study.

<table>
<thead>
<tr>
<th>Rank of Value-Added Skill, Knowledge, or Ability</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Better written and oral communication skills</td>
<td>4.62</td>
</tr>
<tr>
<td>2. Better developed leadership skills</td>
<td>4.49</td>
</tr>
<tr>
<td>3. Improved supervision and management skills</td>
<td>4.13</td>
</tr>
<tr>
<td>4. Understand how business decisions affect technical decisions</td>
<td>4.12</td>
</tr>
<tr>
<td>5. Working knowledge of project management</td>
<td>4.07</td>
</tr>
<tr>
<td>6. Understand how technical decisions affect business decisions</td>
<td>4.04</td>
</tr>
<tr>
<td>7. Work in cross-functional teams with other engineering majors</td>
<td>3.85</td>
</tr>
<tr>
<td>8. Work in cross-functional teams with business majors</td>
<td>3.73</td>
</tr>
<tr>
<td>9. Understand the engineer's role in corporate competitiveness</td>
<td>3.72</td>
</tr>
<tr>
<td>10. Internship with a company</td>
<td>3.64</td>
</tr>
<tr>
<td>11. Read and understand financial statements</td>
<td>3.46</td>
</tr>
<tr>
<td>12. Working knowledge of costing methods and cost accounting</td>
<td>3.41</td>
</tr>
<tr>
<td>13. Participate in preparing a business plan for new ventures and products</td>
<td>3.40</td>
</tr>
<tr>
<td>14. Working knowledge of enterprise database systems</td>
<td>3.35</td>
</tr>
<tr>
<td>15. Working knowledge of concepts such as MRP, ERP and e-commerce</td>
<td>3.34</td>
</tr>
</tbody>
</table>

Table 1: Skills Valued by Employers of Engineering Students
Items ranked on a scale of 1-5, where 1=Very little value added to the company, 2=Some added value to the company, 3=Good added value to the company, 4=Moderately high added value to the company, and 5=Very high added value to the company
The ABET requirements and the survey data show that engineering students have to acquire skills such as decision-making, team working, communication, ethics, and the ability to work in global businesses in addition to strong engineering and technical skills.

How has the education establishment reacted to the need for educating engineering students to face the challenges of a global economy? The National Science Board states that the number of science and engineering students is dwindling and the shortage of technically skilled workers is very high. U.S. universities lose 40 percent of freshmen students admitted to engineering programs by the end of their sophomore year and employers chide schools for not providing the skills needed. These observations show that the education establishment is not doing an adequate job of educating the engineering students to meet the challenges of the global economy. This in our opinion is because the appropriate educational materials that bridge the gap between theory and practice are not available to the educators. The National Academy of Sciences stresses that engineering educators should introduce interdisciplinary learning in the undergraduate curriculum and explore the use of case studies of engineering successes and failures as a learning tool. Based on this premise, we have been working on a project to develop innovative educational materials as part of the Laboratory for Innovative Technology and Engineering Education (LITEE). This paper describes the project goals, summary of some of the case studies that have been developed, methods to integrate these case studies with theoretical materials, and evaluation of implementing these materials in freshman engineering classrooms.
Establishing Project Goals

Information technology is essential for solving critical national problems in areas such as science and engineering, the environment, health care, and government operations; but new fundamental understanding is required to make optimal progress\textsuperscript{vii}. Information technology tools are used in industry to simulate, visualize, model, and experiment with complex real-world scientific problems. General Electric has created a web-based tool, called turbine optimizer, that enables the operator of any GE turbine to compare its performance with that of other turbines of the same model everywhere in the world. The tools show the operator how to improve the turbine's performance and how much money that improvement would be worth, and it lets the operator schedule a service call to make the improvement happen\textsuperscript{viii}. In recognition of this change in industry expectation, various institutions are seriously looking into modifying their curriculum\textsuperscript{ix}. For example, the mechanical engineering department at MIT has been transforming the undergraduate mechanical engineering curricula from one primarily based on physics to one based on physics, information science, and biology\textsuperscript{x}. Therefore, the first goal of this project is to develop course materials that introduce engineering students to the complexity of real-world problems and show how engineering companies are working in the information age.

The teaching of domain-specific knowledge has long been recognized to be the primary objective of school and college education, but many students lack the breadth of knowledge and skills that are fundamental to the practice of their profession\textsuperscript{xii}. There is now a growing realization among educators of the need to put a greater emphasis on imparting higher-level cognitive skills (e.g., reasoning, critical thinking, decision making, problem identification, and problem solving). A variety of national reports\textsuperscript{xii} have also
stressed the importance of teaching such skills to all levels of students. The learning experience must move from lecture as a dominant mode to include a significant level of active learning approaches. The relative neglect of teaching of higher-level cognitive skills is due to two ill-founded assumptions: (a) that these skills cannot be taught and (b) that they need not be taught. Evidence is accumulating that both assumptions are wrong: higher-level cognitive skills can be improved by training, and it is not safe to assume that such skills will emerge automatically as a matter of development or maturation. Therefore, the second goal of this project is to develop course materials to improve the higher-level cognitive-based problem solving skills of the students.

In companies, engineers and managers are increasingly involved in teamwork and use information technologies to interact virtually where the members are located at different places. It is critical to provide a similar experience to engineering students so that they are better prepared to work in the information age. Today 21st century organizations are made up of virtual teams and network of teams, the latest stage in the evolution of organizations since the 19th century. For example, geographically separated development groups working in a virtual environment are essential in order to create a 24-hour software development cycle that is essential in the information age.

Therefore, the third goal of this project is to develop multi-media/web-based materials that help visualize how teams of engineers and managers solve real-world problems in virtual environments.

**Development of Multimedia Case Studies**

In order to fulfill these goals, we were able to obtain funding from the National Science Foundation and developed a project team that has been working together with
industries to develop case studies. The team has developed ten case studies. The selection of the case studies was influenced by the following factors:

- Interest and enthusiasm of industry partners to develop the case studies
- The case has to describe a problem that had a decision focus
- The case had to include the use of engineering formulae/charts/processes in solving the problem
- The company had to be willing to share the raw data with the researchers and had to agree for their publication and subsequent use by students

Due to limitations in space, we discuss briefly some of the case studies that were used in freshman classes.

(a) **Della Steam Plant Case Study**

The Della Steam Plant Case Study involves three principal characters - Sam Towers, the plant manager, Lucy Stone, the engineer who represents the turbine-generator manufacturer (OEM, Original Equipment Manufacturer), and Steve Potts, the engineer in charge of predictive maintenance. The Della Power Plant produces and sells electricity generated by turbine-generator units. A turbine-generator unit weighing 120,000 pounds was being restarted after a two month maintenance service. When Lucy took the unit up to a high speed for an overspeed trip test, the unit started to vibrate heavily, causing the building to shake. Many employees became apprehensive and started to back away from the unit. Fortunately, it tripped out and rolled to a stop. Lucy noted from shaft rider probe readings that it was a 17 mil overall vibration. Since this was very close to the 22 mil clearance allowed between the shaft and the bearing, she anticipated the possible breakage of some parts. She therefore recommended to Sam Towers that the
unit be disassembled, the parts checked, and any broken parts replaced before the unit was retested. Her recommendation would cost the company $900,000.

Steve disagreed with Lucy's recommendation based on the readings shown by the proximity sensors he had attached to the turbine-generator unit. He thought that the problem was due to oil whip and would correct itself if the unit was allowed to run for 24 hours. He recommended to Sam Towers that the turbine-generator unit be restarted immediately. The plant was facing tight maintenance budgets, and Steve's recommendation would result in negligible costs if there were no problems during restart. However, if the unit failed during restart, the company would have to replace the entire unit, leading to a potential cost of $19.5 million.

Sam Towers, the plant manager, was in a quandry since this was the first time his maintenance engineer and OEM engineer had disagreed on a major maintenance problem at the power plant. He had to decide whether to restart the turbine-generator unit or shut it down, taking into account a wide range of financial, technical, and safety issues.

This case study was developed with the cooperation of an executive in charge of predictive maintenance at the central office of a power plant. Data was gathered through visits to the plant and interviews with the engineers concerned. This was then integrated with additional technical, financial, personnel, and risk information in order to create a draft of the case study. A CD-ROM was developed where we provide a realistic experience of the vibration problem that occurred in the power plant. This was done using a rotor-kit to simulate the vibrations, and the problem statement narration was done by the engineer who actually worked on the predictive maintenance aspects discussed in the case study. In addition, the CD-ROM includes photographs that showed the severity
of the problem and the consequences of vibrations that can lead to failure of the turbine blades. In addition, competency materials that describe issues in deregulation, vibration, power generation, etc., are included in the CD-ROM.

(b) **Solid Rocket Booster Field Joint Design**

*Challenger STS 51-L Case Study* illustrates the ethical, safety, reliability, risk, scheduling, and cost factors that were involved in the field joint design of the Solid Rocket Booster for NASA’s Space Shuttle. Joe Kilminster, the Vice-President for Space Booster Programs at Morton Thiokol, Inc., convened a teleconference in the MTI conference room on January 27th, 1986. MTI had successfully created the Solid Rocket Booster, the first solid fuel propellant system, for the NASA Space Shuttle and it had worked satisfactorily in all 24 previous Shuttle launches. Although MTI and NASA had encountered problems with the Solid Rocket Booster field joint in the past, these seemed to have been resolved by using larger O-rings and thicker shims. Thus, during the teleconference on January 27th, Mr. Kilminster was surprised to learn that MTI engineers wanted to reverse the decision of the NASA Flight Readiness Review and persuade MTI and NASA management that Flight 51-L should not be launched the next day. MTI engineers were concerned that the possible effects of the freezing temperatures on the SRB field joint could cause major problems within the Space Shuttle systems. As the teleconference proceeded and the engineers and managers debated the issues, it became clear to Mr. Kilminster that a difficult decision must be made. MTI would have to decide whether or not to recommend that NASA launch the STS 51-L, the *Challenger*.

This case study was developed from published literature and visits to NASA. Roger Boisjoly, an engineer involved in the Solid Rocket Booster design at MTI, also
reviewed this case study. The STS 51-L case study included in the CD-ROM brings to the viewer the technical details of the design of the solid rocket booster field joints using a timeline starting with the initial design process in 1972 and ending in 1986. A video was developed that describes the different stages of a solid rocket booster (SRB) and how NASA and their contractors assemble these stages. It brings out some of the technical details involved in the design and implementation of the SRB. Also, we have included footage that shows the O-ring used in the field joint and how it is actually placed in the SRB. In order to explain the phenomenon of joint rotation that actually caused the Challenger accident, we have developed an animation using Solid Works. The animation shows the field joint rotation in a realistic manner. We have also included footage that shows different tests that are done by NASA and their contractors in order to qualify segments of an SRB before they are assembled. The CD-ROM for this case study includes many photographs and animations that demonstrate the technologies clearly and effectively.

(c) Lorn Textile Manufacturing Inc., Case Study

This case study is based on an accident that occurred at WMS Clothing in 1991. A man lost three fingers on his left hand during a routine maintenance procedure when the Lap Winder he was working on suddenly started up. He went through extensive medical treatment that WMS Clothing covered as part of their worker's compensation plan, but was now seeking compensation for the pain and mental suffering he had experienced, suing the manufacturer of the Lap Winder, Lorn Manufacturing, for negligence in the design and manufacture of their product.
In a case such as this, if the manufacturer is found guilty of negligence they are 100% at fault and owe the plaintiff damages, which in this case could be as much as $400,000. However, if it is found that the plaintiff knew of the risk and still went ahead with the dangerous action, then the plaintiff is guilty of contributory negligence and the defendant owes nothing. In many states, if it is found that both parties are guilty to some extent, the defendant would be responsible for their share of the guilt; for instance, if the manufacturer is found to be 70% at fault, then he would owe the plaintiff 70% of the damages. However, in the state where the accident occurred, Alabama, if it can be proven that the plaintiff was negligent in any degree, then he is guilty of contributory negligence and the defendant owes him nothing. Two engineering experts testified one for each of the plaintiff and defendant in the case and their testimony is critical in deciding the merits of the case.

A CD-ROM was developed for this case study that includes photos of the textile machinery, details about the gear mechanism, full transcripts of the depositions made by the plaintiff, defendant, and expert witnesses during the court case, and a video of one of the lawyers discussing the case study. We discuss the details in the next section of how the case studies were integrated into the freshman engineering curriculum.

Integration of Case Studies with Engineering/ Business Topics

In this section, we show how these case studies were used to illustrate the real-world connection when discussing some of the engineering/business topics in the freshman course. We present the methodology we used and the developmental process using examples from a book we developed for this freshman introductory level course xvii. One advantage of this approach we found was that the students were able to understand
and appreciate the real-world connection to each of the topics discussed in the class. We worked with experts who are successful in practicing the engineering/business skills discussed in the earlier section (designing successfully, decision making, communicating well, team working effectively, practicing ethical conduct, and developing a good understanding of fundamental business concepts) to develop each of the topic into a chapter in the book. Each chapter explains the topic in a prescriptive manner telling the students what they need to do as an engineer in dealing with that topic. Then it illustrates these topics with examples from real-world case studies that are provided throughout the chapter. The students are also provided with a CD-ROM where they can view photos, videos, and explanations from the real-world case studies described in each chapter. Thus, each “soft skill” described in the chapter is also explained through a case study (real-world example).

The topics covered in the book and the case studies that are used to show the real-world connection in each of the chapters is as follows:

- Successful design (Challenger STS 51-L)
- Decision-making using scientific principles (Della)
- Communicating well in the workplace (Lorn)
- Working effectively as a team (Della)
- Practicing ethical conduct (Lorn)
- Developing a good understanding of fundamental business concepts (Alabama Power)

In addition, individual and group assignments are provided at the end of each chapter so that the students can work as an individual or as a group and assess what the
students have learned. Through this process, we expect the students to master the topics presented in each chapter and see how they are actually applied in solving real-world problems.

**Example of Integration of Topics with Case Study Materials**

In order to explain how the engineering/business topics were integrated with the case study materials, we herein provide an excerpt that describes the importance of iterative nature of design and then show an example from the challenger case study illustrating this principle.

**Elements of the Design Process**

Design is one of the primary tasks that engineers undertake and it is expected to take as much as 30% of an engineer's time on the job. To be competitive in today's global marketplace, products must be developed and introduced to markets faster, with unprecedented demands for high performance and low cost\(^{xviii}\). Even if the engineer’s position is not purely a design position, design skills are still needed in order to manufacture useful products.

The designer needs to keep profitability in mind, while at the same time remaining abreast of emerging technologies so that he/she may maintain and enhance his/her value to the company and produce valuable products. For example, Boeing Corporation designed its 777 aircraft in a paper-less mode. Boeing integrated its Computer Aided Design (CAD) systems so that the 777 design team could access the designs from anywhere in the world and create virtual instead of physical mock-ups. Boeing distributed 2,200 computer terminals to its overall 777 design team. The terminals were connected to one of the largest grouping of IBM mainframe computers in the world. This provided key participants in the design process, ranging from airframe manufacturers in Japan to engine manufacturers in the U.K. and U.S., immediate access to the data. The systems also allowed all involved in the process to be aware of changes as they were made and confirmed. The new design process allowed Boeing to cut its traditional 60 month development time to less than 48 months\(^{xix}\).
Simply designing a product or system is often no longer sufficient. The design process must be iterated often in order to improve quality, reduce costs, and prevent failure. The safety of a product or a system must be considered, as should public opinion. If the design process is not taken seriously, products will not sell, businesses will collapse, and competitors will thrive. To compete effectively with others, good design techniques must be implemented as a tool of continuous improvement. The design process consists of several distinct steps which are shown in the flow chart in Figure 1.

We will illustrate in detail the elements of the design process taking the reader through the design steps used by NASA to design, test, and fly space shuttles. This example will show that engineering design is an iterative process and that periodic redesigns of product and processes are necessitated when products fail.

**Real World Connection: Redesign of the space shuttle**

NASA developed the space transportation system (STS) in the 1970s as the method U.S. astronauts would use to explore space. The major components of the space transportation system include the orbiter, external tank, solid rocket booster, main engine, and orbital maneuvering system engines (Figure 2). The shuttle is made up of...
three major elements: two solid rocket boosters, an external fuel tank, and the orbiter that houses the astronauts. Figure 3 shows the screen shot describing where the students can find more information on the early development of the space shuttle in the case study CD-ROM.

Figure 2 - Line Drawing of the Space Shuttle
The components of the space shuttle are designed and inspected by various NASA divisions including the Earth Sciences Division, Microgravity Science & Application Division, Material Science Division, and the Computer Science Division. (Information about these divisions can be found at NASA’s website www.nasa.gov.) Designing and building a space shuttle is a time consuming process. NASA, along with several other contractors, designs and manufactures the components of a space shuttle.

Although the mission profile and shuttle design were intricately planned, the fiscal environment of the 1970s was austere and the planned five-orbiter fleet was reduced to four. These budgetary issues were compounded by engineering problems that contributed to schedule delays and the initial orbital test flights were delayed by more than two years. The first test craft was the orbiter Enterprise, a full size model of the space shuttle without the engines and other systems needed for orbital flight. The Enterprise was used to check the aerodynamic and flight control characteristics of the orbiter in atmospheric flight. The Enterprise was carried atop a modified Boeing 747 and released for a gliding approach and landing at the Mojave Desert test center. Five of these test flights were used to validate the orbiter’s systems. After the Enterprise test flights were completed in 1977, extensive shuttle ground tests followed. These tests included vibration tests of the entire assembly and tests of the various shuttle parts. In 1977, Morton Thiokol Inc. (MTI) carried out an important hydroburst test that evaluated the safety margin in the design of the steel case segments. Hydroburst tests consist of pressurizing the Solid Rocket Motor (SRM) case with water to 1½ times the maximum expected pressure of the motor at ignition. Although the test showed that the steel case segments met their strength requirement, some joint rotation (gap opening) was discovered.
William Leon Ray was an engineer with Science and Engineering in the Solid Motor Branch at the time and it was his job to pursue any possible problems with the SRB. He became concerned about joint rotation after the hydroburst tests and sent numerous memos in the late 1970s to his manager, Robert Glenn Eudy, urging him to develop a solution to the problem. In 1977, Leon Ray recommended several solutions to fixing the joint rotation problem in a memo, but engineers at Marshall and Thiokol agreed that although the performance of the field joint deviated from expectations, it was an acceptable risk and implemented a few of the recommendations. The Columbia was launched successfully on April 12, 1981. During 1981 to 1986 many more flights were performed until the Challenger disaster on January 28, 1986, stopped the flights and required a thorough reexamination of the design of the shuttle, in particular the SRB.

The SRB joint was completely redesigned and flights were resumed on Sept. 29, 1988 with the launch of Discovery. With the completion of Space Shuttle Mission STS-113 on December 7, 2002, a total of 112 mission had been flown since the first flight in April 1981. On Feb. 1, 2003, however, the space shuttle Columbia was lost on reentry. This necessitated another thorough redesign of the space shuttle. Discovery was launched during July 2005 and returned but with lingering problems.

This example shows the importance of redesigns in engineering design. Each redesign of the shuttle components took more than 2 years. The budget for NASA’s space shuttle was about $3.7 billion during 2003, $3.9 billion during 2004, and $4.3 billion during 2005. The major activities during these years were undertaken to ensure that the space shuttle can return to flight. Further details about the design of the space shuttle are provided in the book as we discuss the engineering design process.

**Development of Chapters including Illustrative Case Study Materials**

Similar to the example shown above, we have developed other topics in the book and use case studies to illustrate these topics. These materials have been implemented in freshman classes and evaluation results are discussed next.

**Evaluation of the Use of Case Studies to teach Freshman Engineering Students**

As part of the evaluation of the effectiveness of the case studies, 120 students in multiple freshman classes over a period of two years responded to two evaluation forms as well as a final evaluation to capture their responses to this class. Following are summary of the evaluation results for individual case studies, the student journals, and the overall course evaluation on an evaluation performed during 1999-2000; these results have been
replicated in other studies that have been performed by the authors and other researchers. Further details could be found in the articles available at www.auburn.edu/research/litee.

The Field Joint on Solid Rocket Booster case study (Challenger case study) received favorable—in fact the highest—ratings (with 1 being not favorable to 5 being favorable) on nine constructs. All mean ratings for the nine constructs exceeded a 3.5 (Tables 1 and 2).

Table 1: Means for Constructs in Evaluation I

<table>
<thead>
<tr>
<th>Interesting and Exciting</th>
<th>Important and Valuable</th>
<th>Instructionally Helpful</th>
<th>Relevant and Useful</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>4.2</td>
<td>4.0</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Table 2: Means for Constructs in Evaluation II

<table>
<thead>
<tr>
<th>Perceived Skill Development</th>
<th>Self-Reported Learning</th>
<th>Intrinsic Learning and Motivation</th>
<th>Communication Skills</th>
<th>Learn from fellow students</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2</td>
<td>4.2</td>
<td>4.2</td>
<td>3.5</td>
<td>4.1</td>
</tr>
</tbody>
</table>

The constructs of Relevant and Useful ($M = 4.32$) and Self-Reported Learning ($M = 4.23$) received the highest mean ratings on the evaluations, with Communication Skills ($M = 3.5$) receiving the lowest mean ratings. Again, the comments were positive, which made this case study experience more emotionally charged and personally relevant.

When comparing the mean ratings of the Della Steam Plant case study (the first of the quarter) with the SRB Case Study (the final of the quarter), the absolute mean ratings on all nine constructs for SRB exceeded those of Della. In fact, the mean ratings were significantly higher for the final SRB case study on five of the constructs—Interesting and
Exciting, Perceived Skill Development, Intrinsic Learning and Motivation, Instructionally Helpful, and Communication Skills. This finding suggests that, in addition to perceiving the benefit and value of the case studies, the students did not tire of the instructional approach, as they became familiar with the methodology throughout the quarter.

**Effectiveness of the Course in Achieving Objectives**

The case study method of instruction appeared to combine theory with practice as well as encourage the use of higher-order thinking skills within the students – the two primary objectives of this particular class. In the individual cases, the students applied their knowledge of engineering design and management issues in making decisions. They had to analyze alternatives, make a choice, and defend that choice—all-important steps in the critical thinking process. Working in teams, they learned from each other. The data from the evaluation seem to indicate that the case study methodology is a worthwhile and beneficial method of instruction for teaching the freshman students. Through positive median and mean ratings, the students indicated their favorable responses to each of the three case studies presented during the course.

New evaluation methodologies are being developed in order to assess the efficacy of the case study methodology to achieve the objectives listed earlier. The data from these studies is being analyzed and will be reported in the future.

**Longitudinal Evaluation**

Case studies focusing on real-world problems were central in a select number of introductory engineering classes\textsuperscript{xxii}. Students in these classes formed an experimental group whose grade point averages were compared with those of other pre-engineering
students who were not in these experimental sections but instead were in other sections taught using more traditional lecture/discussion approaches. End-of-course evaluations in the experimental classes showed that they were well received by the students and beneficial in helping them achieve course objectives. Benefits extended beyond the experimental class as evidenced by significantly higher GPAs in subsequent terms in contrast to the GPAs of the comparison group. A most important finding is the differential rate at which the experimental pre-engineering students were admitted to study in a professional engineering program. Those pre-engineering students were admitted in much higher proportions than were their comparison counterparts.

**Conclusions**

The ABET requirements and the survey data in the introduction section show that engineering students have to acquire skills such as decision-making, team working, communication, ethics, and the ability to work in global businesses in addition to strong engineering and technical skills. The chapters in the textbook discuss the theories on how to acquire these skills and then use case studies to illustrate the theories. In addition, team working assignments are provided at the end of each chapter so that the students can practice their acquired skills on other case studies provided in the textbook. We expect that they will have further opportunities in other courses to hone these skills further. Evaluation of the use of these materials in freshman classrooms show that these materials have the potential to improve the GPA of the students and help retain them better in engineering programs.

A future research is to develop more effective tools to assess the efficacy of the case studies on learning. Dr. Jeffrey Katz from the Department of Psychology and Dr.
Howard Clayton from the Department of Management at Auburn University are working with Drs. Raju and Sankar to develop new assessment instruments. Two types of tools are being used to assess the efficacy of the case studies on learning, namely conventional multiple choice tests (MCT) and a new approach based on the Print Exposure Checklist (PEC). PECs are simple yes/no recognition tests which, to our knowledge, have never before been used in engineering classrooms. Once these tools are developed and validated, it will be possible to measure more accurately the improvement in skills that result from the use of the case study methodology.

The research results point out to the potential of the case study methodology to address many of the ABET 3 a-k criteria well. As the case study methodology is more widely used in engineering classrooms around the country, we expect other studies to report on the efficacy of using these materials in the classrooms and help instructors interested in implementing innovative educational materials choose the appropriate materials.

**Acknowledgements**

We thank the Division of Undergraduate Education, National Science Foundation for funding the case study development and dissemination activities under the grants # 9752353, 9950514, 0001454, 0089036 and 0442531. In particular, we thank Dr. Russ Pimmell, program director, NSF for his valuable feedback and comments. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation. Mrs. Carlise Stembridge and Mr. Bill Stenquist, Senior Sponsoring Editors at McGraw-Hill were responsible for many of the changes that were made to the chapters and we thank them for their comments and help.

---

iii Study done by J. Bryant, Director, Thomas Walter Center, Auburn University, 2001, www.eng.auburn.edu/BET


xvii A textbook is under preparation under the sponsorship of McGraw-Hill Publishing, Inc.


xx During 2004, the orbiter is built by Rockwell International’s Space Transportation Systems Division, Downey, Calif., which also has responsibility for the integration of the overall space transportation system. Both orbiter and integration contracts are under the direction of NASA’s Johnson Space Center in Houston, Texas. The SRB motors are built by the Wasatch Division of Morton Thiokol Corp., Brigham City, Utah, and are assembled, checked out and refurbished by United Space Boosters Inc., Booster Production Co., Kennedy Space Center. Cape Canaveral, Fla. The external tank is built by Martin Marietta Corp. at its Michoud facility, New Orleans, La., and the Space Shuttle main engines are built by Rockwell’s Rocketdyne Division, Canoga Park, Calif. These contracts are under the George C. Marshall Space Flight Center, Huntsville, Ala.
