# AC 2011-417: IMPLEMENTATION AND ASSESSMENT OF CASE STUDIES IN A FRESHMAN ENGINEERING PROGRAM

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# Implementation and Assessment of Case Studies in a Freshman Engineering Program


## Abstract

This paper reports on a subset of work carried out on a project to extend the previous efforts of implementing and assessing case studies to twelve university partners that broaden the scope to cover all engineering disciplines, as well as the NSF Materials Digital Library. This specific assessment focuses specifically on the activities the Department of Engineering Fundamentals at the University of Louisville, where case studies are used in a first year course titled *Introduction to Engineering*.

Case studies require students to synthesize the facts and engineering principles they have learned, and combine them with their broader education in the arts, humanities, and sciences. Case studies tie together technical, ethical, and procedural aspects of engineering and require students to undertake higher order thinking in order to synthesize the relevant issues. As a result, the case studies integrate ethics and procedural/professional issues into courses. In the case of a first year course, case studies introduce the engineering profession.

Case studies used in this first year course have included some basic design case studies regarding local failure and design investigations, such as damage due to blasting and problems with tunneling. More involved case studies include the Hyatt Regency walkway collapse and the problems the Hubble Space Telescope experienced and the engineering of the subsequent repairs. A non-failure case study used in the course involves the design of a wastewater treatment process.

All case study activities involve active learning via teamwork, but a special activity was added for the case study of the collapse of the Hyatt Regency walkways in Kansas City, Missouri, in July 1981, where 114 people were killed. Students participate in a mock hearing before a Professional Engineering Licensure Board to determine which entity involved in the design and construction of the walkways was most responsible for the disaster. Groups of students are assigned to take the role of the engineer, contractor, and other entities and must defend those positions. Case studies such as the Hyatt Regency collapse can reinforce the importance of professional licensure by illustrating the responsibilities of the Engineer of Record.

It is anticipated that the use of case studies with first-year students will positively impact retention, especially for those who don't easily relate to engineering as a career, and will also facilitate career choices and emphasize the common ground of practice among students in various engineering disciplines. Student surveys and performance are being recorded to determine the effects of using case studies with first year students.


## Background

Lessons learned from failures have substantially affected the practice of many engineering disciplines. The history of development of engineering practice is, in large part, the story of failures and of the changes to standards and procedures made as the result of forensic analyses. In fact, it is common in modern engineering practice to review projects, systems, and incidents to identify root causes for either success or failures and then share these findings with others. This continuous improvement in how engineering is practiced is a core feature of the profession. Case studies of engineering activities (successes and failures) offer the student a unique insight into the actual practice of engineering. In addition to technical issues, concepts such as professional and ethical responsibility are highlighted by case studies.

Case studies also have the potential to reach students who have difficulties relating to the engineering profession. One of the sources of problems commonly identified for women students is that they often don't have the background of helping their parents with hands on projects [1]. This issue might also apply to many students who grow up in urban environments, or without fathers. Overall, fewer and fewer engineering students are entering college with prior hands-on technical experience.

If case studies are introduced and taught properly, students now have something concrete to use as a foundation for theoretical knowledge, and help build their engineering identity. This is particularly important for the students who don't have engineers in their family. When they tell their families about what they are learning at school, concrete case studies would be much easier for them to explain than abstract theories. For example, "today in class we learned about the key technical factors involved in the Minneapolis I-35W Bridge Collapse." This is particularly important in courses for freshmen, such as the introductory course discussed herein. This paper begins with a historical introduction of the use of case studies in an introductory course, briefly updates the literature specific to use early in the undergraduate program, describes three case studies used in the *Introduction to Engineering* course at the University of Louisville, emphasizing the mock trial that was added to the Hyatt Collapse Case Study, presents survey results from 2009 freshmen class, and expected results of future work.

## Introduction

The use of case studies for the first year course at University of Louisville was initiated when a two-hour introductory engineering course was re-designed in 2007 by an ad-hoc committee appointed by the Dean of the Engineering College. All units in the university are required to offer an introductory course that introduces students to campus, discusses diversity, and engages students in critical thinking. The engineering college at University of Louisville incorporated those topics into a course that also introduces the seven different engineering disciplines offered at University of Louisville, as well as engineering design, teamwork, ethics, and professionalism. A major topic discussed in the re-design of the course was how to incorporate "hands-on" and design projects since much literature [2,3,4,5] highlighted the importance of having design projects early in the curriculum to foster interest and improve retention in engineering.

Case studies offer the best of both worlds. Well-developed case studies offer opportunities to gain in-depth knowledge of engineering systems and design, to consider ethical issues, to work in teams, and to gain many of the same benefits of discovery offered by "hands-on" projects without the cost, storage, and other over-head associated with hardware design. In fact, a female student on the committee suggested case studies. She had experienced them in an industrial sponsored summer camp, and felt case studies offered a great introduction to the engineering profession. Two or three well-designed case studies can appeal to all students more easily than trying to select "hands-on" design projects that are most often discipline specific. The committee decided to include three case studies in the fall of 2007, the first time the re-designed introductory course was offered. It has since been narrowed to two to allow for more in-depth work on each one as well as a concentrated focus on critical thinking, part of the Quality Enhancement Plan required by University of Louisville's SACS accreditation.

Of importance to the committee was the inclusion of cases that did not always result in death and destruction. Just as young people are motivated to study medicine by seeing the opportunities to save lives, not read about the many ways they might cause loss of life; the committee felt young engineering students might be turned off by studying only failures that result in loss of life or environmental destruction. As previously mentioned, a huge part of engineering is learning from mistakes and successes, and not all mistakes result in catastrophe. In fact, the first case now used is simply to choose a reasonable solution for a process design to a realistic industrial wastewater treatment problem. The only case study that involved loss of life was the Hyatt Collapse case study. It was selected because the engineering principles involved are fundamental to all engineering disciplines. The final case study that has been used is the Hubble Telescope case study. The Hubble Telescope case study was developed from information available in the literature and current news. This case study demonstrated the way engineers "fix" things that fail, and how many complicated systems and organizations worked together in launching an international project. The Hubble is complicated enough that it has been discontinued for now, with faculty choosing to focus more in depth on the first two case studies. However, it offers much for students, and may be substituted for one of the other case studies or added as the course changes.

**Case Studies in the Literature**

Many authors over the past two decades have pointed out the need to integrate lessons learned from failure case studies in engineering education [6,7,8,9,10,11,12,13,14]. The case for including failure case studies in the engineering curriculum has been made by several authors, including Delatte and Rens [15], Delatte [16], Carper [13], Carper et al. [17], and Carper et al. [18]. Over the years, the ASCE Technical Council on Forensic Engineering (TCFE) has carried out several surveys of civil engineer programs across the U.S. One common theme of the responses was that there was considerable interest in including failure case studies in courses, and that there was a lack of available materials suitable for classroom use. [16,19] As a result, considerable effort has been put by TCFE into developing case study materials suitable for classroom use.

The use of case studies is also supported by the latest pedagogical research. *From Analysis to Action* [19] refers on page 2 that textbooks lacking in practical examples is an emerging weakness. This source refers specifically to breadth of understanding, which may be achieved through case studies. Another issue addressed [19] (p. 19) is the need to "incorporate historical, social, and ethical issues into courses for engineering majors." The Committee on Undergraduate Science Education in *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* [20] proposes that as many undergraduate students as possible should undertake original, supervised research. *How People Learn* [21] page 30 refers to the need to organize knowledge meaningfully, in order to aid synthesis and develop expertise. Raju and Sanker [22] point out the use of case studies for engineering students to learn the real-world issues of marketing, finance, communication, and interpersonal relations. They advocate the need to develop interdisciplinary case studies so that innovations happening in the engineering world can be communicated to students in the classroom.

**Case Studies and First Year Courses**

First year engineering courses have been modified in recent years to improve retention by making explicit connections to engineering practice and engineering careers, as opposed to a curriculum that just emphasizes mathematics and science core courses [2,3] and to integrate science, mathematics, and the engineering disciplines. [4] Other research has shown that project based design activities can be advantageous in the first year. [23] Kilgore et al. has examined, in a longitudinal study, how first year engineering students approached design tasks and discussed the fact that female students were more context-oriented than male students. [24] Fortenberry et al. [5] summarizes much of these retention efforts and concludes that continued efforts at retention should recognize that "fewer students leave engineering when their education links concepts to real-world practice". Case studies offer a way to easily bring forth contextual factors and to link to the real world.

Recently, Sankar et al. [25] published an informative literature review of soft-skill development and results of a research study using multiple instructional methodologies in two different introductory engineering classes. The research question was: Which methodologies enhance students' perceived higher-order cognitive skills, team-working skills, attitude toward engineering, and impact on future work environments (soft-skills)? Their research (based on one semester only) showed that case studies made a major difference in students' perceived soft-skill development in an introductory engineering course. Results from a similar study of first year engineering students [26] suggest that the use of multimedia case studies in minority classrooms has the potential to improve perceived leadership skills more so than traditional teaching methods. Wise et al. [27] published a study that followed a group of engineering undergraduates through their first four years of education at a large, land-grant university. They found that active learning classrooms with team-based design projects had a positive effect on intellectual development of first year students, but that the effect does not last without further enriching experiences. Case studies are active and team-based, and easily incorporated into courses past the freshman year to maintain intellectual development and to improve critical thinking skills.

**Case Studies in an Introductory Engineering Course**

All incoming students to the engineering program are required to take the *Introduction to Engineering* course. The goals of the course are to introduce the new students to college campus life and resources, make the students aware of the different disciplines of engineering that might interest them, give them a feel for what engineers do, and introduce them to engineering software that they may use in school or profession to solve technical problems.

Case Studies are used in the "Introduction to Engineering" course as a way for the incoming students to experience and evaluate various aspects of the engineering profession. A major objective of the case studies is to expose students to some aspects of the modern practice of engineering, namely: teamwork, problem and data analysis, design creation, presentation and defense of a designed solution, and professional ethics. Currently, two case studies are used; experience has shown three case studies are too much for sufficient depth of each. The case studies are carefully structured to actively engage students in the engineering activities of critical thinking and analysis of a complex problem. Highly technical aspects of engineering requiring training not yet received by the students are avoided.

The class meets for two hours twice per week. Three sections (approximately 30-35 students each) meet at one time with one or more faculty members and three teaching assistants (TAs). Presentations are made to the entire group but "break-out" sessions are held in smaller rooms with only one section meeting with their TA. Instructors circulate among the three smaller rooms to assist and answer questions.

Fundamental to the case study work in the introductory engineering course is teamwork. Evaluating teamwork poses challenges. To insure teams work together, team members sign a contract that stipulates a non-contributing member's grade will be adversely affected. If a student has unexcused absences and fails to do the assigned work, a zero grade is given on that portion of work. Faculty and teaching assistants monitor teamwork and intervene to assist dysfunctional teams. Teams of 4-5 students are created by random assignment at the first of the semester.

**Case Study One – Wastewater Treatment Process Development**

The first case study introduced is Wastewater Treatment Process Development which involves researching and proposing the best possible solution to a real world manufacturing plant's wastewater problem. The problem is a real life example of a typical open-ended engineering problem, constrained by time, money and safety issues. In this study, the students are given a simple flow sheet and process description of the manufacturing process. This information describes the sources of the wastewater and the contaminant and level of contamination in each of the sources. The students are challenged to first understand the problem and question their instructor for more information if they need it.

After understanding the problem, students brainstorm for solutions and then perform individual research on potential approaches to treat, reduce or eliminate the wastewater. After each team member presents their individual research to their team, the team reaches an overall consensus on which approach to pursue. The teams are given some guidance on how to critically analyze each potential alternative. They are prompted to evaluate the potential of each approach to meet the plant's requirements of timing, safety, minimum cost of operation and investment, and high probability of success. Since students don't have the skill set or time to rigorously calculate and estimate these items, they are given guidance about how to roughly judge each. For example, to help the students evaluate the safety of a given solution approach, students are directed to determine if the approach requires high temperature, high pressure, or toxic chemicals. Similar guidance is given to help in evaluating and supporting their conclusions on their proposal's ability to meet the other plant's requirements.

To culminate this case study, each team prepares a presentation for "plant management" proposing, explaining, and defending their recommendation for solution of the wastewater problem. This presentation is given to their entire section (35 students), with the students in the audience playing the role of management. As such, they are asked to evaluate each team's presentation against a critical thinking rubric supplied to them.

In this case study, the engineering concepts introduced are: 1. Engineering is usually a team activity; 2. Engineers must be able to effectively research, organize information and communicate conclusions and recommendations to investors, customers, managers, and co-workers in oral and written form; 3. Critical thinking is core to engineering; 4. Thinking can be dissected into parts (or elements) and to be effective at problem solving, one's thinking must include all the elements at the appropriate standard. University of Louisville has as part of its Quality Enhancement Plan to improve the critical thinking skills of undergraduates. The Paul-Elder critical thinking framework [28] is introduced in this course and reinforced in all case studies. The overall learning objectives are: 1. Increase student awareness of the process of thinking during problem solving; 2. Engage in critical thinking in the analysis of a typical engineering problem; 3. Learn how to use elements of critical thinking to create an effective technical document and oral presentation; 4. Work as a team to develop potential solutions to a complex, open-ended engineering problem.

The graded assignments include: team meeting brainstorm session notes, each students' individual one-to-two page report on potential solutions to the problem, research conducted and recommended approach, (due session two) and a short (10 minute) team presentation summarizing the problem, approaches researched, recommended solution and bases for the recommendation.

In session one, engineering as a profession is introduced, teamwork in engineering and how to brainstorm in problem solving is explained and discussed, and the wastewater problem is introduced. The engineering concepts and learning objectives of the case study are shared and associated with the specific class activities and assignments. In this way, the students are not only informed of what is expected of them, but how each of the activities pertains to an important aspect of the engineering profession. In the breakout session, teams discuss the problem, formulate potential areas for research, organize their team, and make individual research assignments. Students turn in (via Email) their brainstorm results to their TA and other teammates.

In the first part of session two, critical thinking via the Paul-Elder framework is introduced and students are engaged with a short critical thinking exercise. Then, in the breakout session, teams get together and work on the case study. Based on their individual research for potential solutions to the case study problem, students summarize their research findings and recommendations in a paper that they read to their teammates. The teams use the evaluation criteria developed from the Paul-Elder model for evaluating a technical document. Afterwards, teams discuss each recommended approach and come to a consensus as to the team's recommended solution. After reading all the papers, the team discusses the papers, sharing thoughts not only about which solution among the team seemed to be the "best" solution but if they had enough information from the papers to reach a logically defensible conclusion on which solution they as a team could support. If more information was needed to reach a reasoned conclusion, the teams were expected to attempt to get more data or at least limit their conclusion based on existing data and reference any important missing information and assumptions in their thinking. Finally, the team creates a PowerPoint presentation that's purpose is to convey pertinent information to their supervisor (TA) so a business decision can be made as to whether to invest time, money, and organization effort to implement their proposed solution.

In session three, each team gives their presentation to the breakout section. Other teams listen, take notes, and evaluate other teams' proposals against their own. After each presentation, the audience is expected to ask questions. Each breakout group will vote on the best team presentation and solution proposal.

This case study is continually revised based on student, TA, and faculty feedback. The first time the case study was used, potential solutions were supplied to the students and they were led through the steps to possible solutions. Such a guided approach resulted in the students reading the assigned materials with little personal engagement or creative thinking. Students enjoyed conducting their own research on potential solutions to the problem presented in this case study. With this more open approach, the students participated with more creativity and engagement.

A critical thinking rubric developed by engineering faculty at University of Louisville was provided to the students and direction was given for them to evaluate their papers and presentations against the rubric to ensure their work incorporated evidence of critical thinking.

**Case Study Two – Hyatt Regency Disaster**

The second case study used was the examination of the failure of the skywalk at the Hyatt Regency Hotel in Kansas City that killed 114 people and injured many others. This is a common case study used in engineering training, but usually used in higher level (particularly civil engineering) courses. This failure is beneficial for incoming students because the technical reason for the failure is based in simple statics, a course all engineering majors take. However, understanding how the deficient walkway supports were approved to be constructed and installed is challenging, particularly for young students that have not experienced working in a large team on a complicated task. Since most incoming students have little knowledge of the complex relationship of design, fabrication and construction steps in projects, it has been found that some instruction in the roles and responsibilities of each entity (owner, designer, architect, fabricator, general contractor, etc.) is required for them to be able to fully analyze the problem.

The concepts introduced in case study two are: 1. Engineering is often a team activity, particularly in the project, design, build and operate aspects of engineering work; 2. Engineers conduct research, summarize data, reach conclusions from the data and determine logical inferences and recommendations for action; 3. Systems must be in place during all stages of engineering work to ensure quality and accuracy of the work; 4. Engineers formulate defensible and logical opinions based on data; 5. Engineers communicate findings and opinions (in written and oral formats) in a concise, complete, clear and accurate manner; 6. Engineers hold positions of responsibility; and finally, 7. Engineers must hold paramount the safety, health and welfare of the public in all aspects of their work.

The learning objectives of this case study are: 1. Provide an opportunity for individual research of a past engineering failure and determine the key learning from that failure; 2. Work as a team to fundamentally understand a problem and why the problem occurred (The goal is to understand not only technically why it occurred but why the technical errors were not discovered and corrected.); 3. Engage in critical thinking and analysis to identify what technical error(s) occurred and to try to determine what system error(s) existed that allowed the technical error to go undetected, and finally, logically analyze the case to determine what personal errors were made by the people involved in the case; 4. Increase student awareness of the roles and responsibilities of working in the Engineering Profession; and 5. Use the elements of critical thinking to create a defensible, logical position on the question of which entity involved in this case was most responsible for the failure occurring.

The graded assignments include answers to individual research questions on aspects of the case the student researched, a readiness test to ensure each team has complete and accurate information, and the mock hearing defense prepared for each team.

The Hyatt Case Study is introduced in session one by first giving an overview of the learning objectives and a description of how those objectives and student assignments are to be accomplished. An introductory PowerPoint presentation gives the basics of the situation which is followed by a news coverage video to attract students' interest and concern and to demonstrate the very real importance of this case study. Each student (as part of a team) is assigned different material to read and individual questions to answer for their team. The readings are published papers reported in the literature covering this disaster.[29,30,31,32] Students are charged to come prepared in session two for a readiness test and for a team discussion answering, "What was the fundamental nature of the problem that caused the collapse? Was the problem a technical problem or a system problem? Who was most responsible? Who shared some responsibility?"

In this second class session, students take a readiness test, turn in answers to their individually assigned questions, and then listen to a presentation of the roles and responsibilities of each of the entities (owner, designer, architect, fabricator, general contractor, etc.) involved in the design and construction process given by instructors and further discussed with teams and TA. The first teaching objective is to identify what technical error(s) occurred and then dig deeper and try to determine what system error(s) existed that allowed the technical error(s) to go undetected. Students are challenged to analyze the case to determine what personal errors were made by the people involved in the case and who should be held most accountable in their opinion. The opinions are to be formulated based on complete and accurate information and logical reasoning on this information.

Next, a discussion of the mock hearing procedures and protocol takes place. The hearing will start with an oral account of the incident and the purpose of the hearing, which is to assign blame. Defendants will be called to offer defense in the following order: Gillum (Engineer of Record (EOR)), Duncan (Project Engineer), Owner, General Contractor, Fabricator, Testing Agencies (considered as one entity), and Sub to Fabricator. Each defendant (team) will get five minutes for their opening statement and defense witness questioning. Defense witnesses can be the defendant, experts (Pfatteicher, Luth, or Moncarz/Taylor/Fellow) or other involved person/entity.  After defense questioning is complete, each other interested party will be allowed one minute for one question to any called defense witness.  If a witness is called later by another group in defense of another person, another cross-examination question can be asked.  The defendant will be allowed to close with a one minute closing statement, for a total of 12 minutes for each group in defense of each person or entity.  The three member PE licensing panel will be allowed to question the defendants at any time and will have authority to extend or discontinue time limits for defendants.

In the mock hearing, students assume roles of each of the entities involved.  Teams are assigned to represent the Engineer of Record, Project Engineer, Owner, General Contractor, Fabricator, Testing Agencies, and the Sub to the Fabricator.  The teams must develop a defense for the entity that they represent.  As such, each team must create a defense document that must contain:  An opening statement with the defense strategy clearly stated with clear evidence used to prove the innocence of the team's entity or entities; a defense witness list where the team identifies who will be called in the team's defense as well as explain how the witness testimony will support the defense strategy including planned questions with expected answers; a cross examination witness list where team identifies who will be cross examined and how this witness testimony will support team's defense strategy including planned questions with expected answers; and a closing summary statement which clearly explains how the testimony presented exonerates the person or entity the team represents or at most shares some responsibility for the disaster. During this teamwork, the individual obtains experience at communicating research, discussing other relevant information provided by other team members, and reaching sound conclusions based on accurate information.

In the third session, students turn in drafts of their team defense document, review drafts with their TA, work to improve the document by reviewing case facts and clarifying their defense strategies, and revising witness questions.

The goal of the hearing is to present and weigh the evidence regarding the Hyatt disaster and to come to a conclusion as to who was most responsible for the failure.  In the hearing, students take on the roles of the various entities that had a part in the design, fabrication, and construction of the Hyatt Hotel.  As such, the students are challenged to think critically to create a defense argument using factual case history information that demonstrates that the entity they represent is not responsible for the disaster.  In defense of their entity, the students create an opening statement for the defense, call up to three defense witnesses/experts, and a defense closing summary statement.  In addition to defense, students are allowed to cross-examine witnesses called by other defendants and must prepare questions in advance.  The aim of the cross-examination is for the students to identify and clarify weaknesses in the arguments and positions presented by other entities and to make sure information given is complete and accurate.  Faculty members from the Civil Engineering Department serve as additional members of the Licensure Board along with faculty teaching the course.  These board members re-direct students if they make obvious factual or critical thinking errors and point out final issues with the case.

In the fourth and final session, the mock hearing is held.  A mock PE Licensure Board (three member panel composed of engineering professors) conducts the hearing and controls the proceedings.  This hearing starts off with a reading of the purpose of the hearing.  All students are expected to represent their assigned entity. Before the hearing starts, students are selected and then informed of their selection for active participation in the hearing. Those students not identified for an active role in the hearing serve as expert witnesses and as the jury pool. At the conclusion of the hearing, students' opinions as to the degree of responsibility of each of the parties are polled using DyKnow®. The client/server software named DyKnow® is available from the company of the same name, which is a leader in interactive education that combines sound teaching with intuitive software to create flexible and effective solutions for teaching and learning. Dyknow® was designed to be an interactive education tool that would allow for student feedback as well as fostering a collaborative learning environment. The case study concludes with general discussion between the students and professors regarding engineer's roles and responsibilities.

Though students are much more actively engaged and report enjoying this activity, some challenges remain. Some students are ill-prepared, and others are too shy or too embarrassed to actively engage in the testimony. Efforts continue to improve the defense draft review and to better train the TAs by providing a review and feedback form to use during evaluation for return to each team.

**Case Study 3 – Hubble Space Telescope**

Portions of three class periods of the *Introduction to Engineering* course have been devoted to discussion and activities on the Hubble Space Telescope case study. This case study is currently retired to focus on the first two. However, it has value and can be substituted for either one for variety. If used again, more activities would be added to actively engage students.

The first session introduced the Hubble Case Study via a PowerPoint presentation by the instructor. The presentation was posted on Blackboard ahead of time so students could be familiar with presentation and ask questions. Each team member was assigned specific questions to answer regarding the Hubble case. The questions for each person were detailed in the Blackboard documents. The information to answer these questions was also contained in the posted documents in Blackboard for the case study. Each person was expected to read the required documents assigned to them and be prepared at the next class to take a "Readiness Test". At the next class meeting after the readiness test, a presentation with more information regarding the Hubble case study was given. A breakout session was held where each team discussed the readings with each other. The purpose of the breakout session was to share with team members the answers to each of the assigned questions, come to an agreement as a group on the technical causes of the failures on the Hubble, develop a group summary to describe the Hubble failures and technical causes (what happened, what technically failed), and finally leave with enough information so answers or opinions regarding the overall more important questions that were raised at the beginning of the case study could be answered. Those questions were: 1. What is different about designing and deploying the Hubble Space Telescope that is completely different from the first two case studies? (Wastewater Process Development, Hyatt Collapse); and 2. What is Systems Engineering and why is the Hubble Space Telescope a good case study to teach principles of systems engineering? The final assignment was for each person to prepare a three-page report on the Hubble Case Study due at the beginning of the third class. The report consisted of the following: 1. A group summary of the Hubble Telescope problems and technical causes and why they occurred; 2. Answers to the questions each student was individually assigned to answer; and 3. The student's personal opinion to the two important questions, supported with information, data and logic.

**ABET Requirements**

ABET EAC criterion 3 defines 11 program outcomes that all engineering programs must meet and document. "Engineering programs must demonstrate that their students attain the following outcomes: (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 multidisciplinary 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." [33]

ABET requires that these 11 outcomes be met as part of the undergraduate program. It is a relatively straightforward process to document the technically oriented outcomes. However, it is a little more difficult to address some of the less technical outcomes such as c, f, h, and i.

Programs often struggle with how to document that their graduates understand the impact of engineering solutions in a global and societal context, engage in life-long learning, and demonstrate knowledge of contemporary issues (criteria h, i, and j, respectively). One method of documenting these particular outcomes is to include case studies of failed engineering works in the curriculum. Many case studies show the direct societal impact of failures, and demonstrate the need for life-long learning by highlighting the evolutionary nature of engineering design procedures. It is good to introduce these issues in a first year course.

**Integrating Diversity into NSF Programs, Projects, and Activities**

At present, underrepresented minorities (URMs) in civil engineering and other engineering disciplines consist of women and minorities. This has been identified as a problem of national importance. [34] At the University of Louisville site, for example, the case studies are used in the *Introduction to Engineering* course, which is required for all freshman engineering students. This course in the fall of 2009 had 15.6% minority students (55 out of 354 students enrolled) and 19.8% female students (70 out of 354 students enrolled).

Case studies introduce issues broader than technical engineering principles such as ethics, professional responsibility, impact on the community, communication, etc., which then may aid in engaging these students in a number of different ways. [35] Another reference [36] discusses the important role of self-efficacy in improving cognitive engagement, academic performance, and persistence of female students in science and engineering. The role of failure case studies in enhancing the self-efficacy of student in underrepresented groups is a topic worthy of study.

The results from this project for 2009 will be discussed in the results section. The results investigate the use of case studies to help underrepresented groups improve their interest and achievement in engineering. This will include taking a closer look at effects of using case studies on the self-reported interest and understanding of underrepresented groups.

**Results**

The fall of 2009 *Introduction to Engineering* course at the University of Louisville was presented the following ten-question survey and was completed by the students after the completion of two case studies (Wastewater Treatment, and Hyatt Regency Collapse):

1. How well did the case study Classroom Lectures contribute to your interest in the engineering profession?
2. How well did the case study Group Activities contribute to your interest in the engineering profession?
3. How well did the case study Independent Research contribute to your interest in the engineering profession?
4. How well did the case study Projects contribute to your interest in the engineering profession?
5. How well did the case study Readings and Supplements to the Lectures contribute to your interest in the engineering profession?
6. How well did the case study Classroom Lectures contribute to your understanding in the engineering profession?
7. How well did the case study Group Activities contribute to your understanding in the engineering profession?
8. How well did the case study Independent Research contribute to your understanding in the engineering profession?
9. How well did the case study Projects contribute to your understanding in the engineering profession?
10. How well did the case study Readings and Supplements to the Lectures contribute to your understanding in the engineering profession?

The survey administered was a self-reported Likert scale survey with valid input from the students being: 5-Very High, 4-High, 3-Moderate, 2-Low, 1-Very Low. The ten questions are broken into two categories: Questions regarding change in interest (the first five); and Questions regarding change in understanding (the last five).

**Averages**

The results shown in Table 1 are the average Likert scores reported based on gender for the first five questions. As previously mentioned, the Likert scale was 1-5, with 1=Very Low and 5=Very High.

**Table 1: Gender Based Self-Reported Interest**

| Category | Count | % of total | Lectures | Grp. Act. | Ind. Res. | Projects | Readings |
|---|---|---|---|---|---|---|---|
| Male | 283 | 80.17% | 2.755 | 3.266 | 3.103 | 3.216 | 2.848 |
| Female | 70 | 19.83% | 2.841 | 3.174 | 3.246 | 3.261 | 3.087 |

As Table 1 shows, it is deduced that case study activities benefit female students positively versus their male cohorts, except possibly the group activities. The results shown in Table 2 are the average Likert scores reported based on gender for the questions six through ten.

**Table 2: Gender Based Self-Reported Understanding**

| Category | Count | % of total | Lectures | Grp. Act. | Ind. Res. | Projects | Readings |
|---|---|---|---|---|---|---|---|
| Male | 283 | 80.17% | 3.389 | 3.449 | 3.495 | 3.445 | 3.337 |
| Female | 70 | 19.83% | 3.628 | 3.58 | 3.671 | 3.7 | 3.557 |

As Table 2 shows, case study activities positively impacted female students in their understanding of the engineering profession.

Table 3 reports the average Likert scores reported based on ethnicity for the first five questions on interest in the engineering profession.

**Table 3: Ethnicity Based Self-Reported Interest**

| Category | Count | % of total | Lectures | Grp. Act. | Ind. Res. | Projects | Readings |
|---|---|---|---|---|---|---|---|
| American Indian/Alaska Native | 1 | 0.28% | 3 | 3 | 3 | 3 | 3 |
| Asian | 20 | 5.67% | 2.9 | 3.2 | 3.25 | 3.05 | 3 |
| Black/African American | 18 | 5.10% | 2.778 | 3.278 | 3.111 | 3.278 | 2.833 |
| Foreign | 3 | 0.85% | 2.667 | 3.667 | 4.333 | 3.667 | 3.667 |
| Hispanic/Latino | 6 | 1.70% | 2.833 | 3.333 | 2.667 | 2.833 | 2.833 |
| Unknown | 7 | 1.98% | 2.428 | 3.428 | 2.857 | 3.286 | 2.857 |
| White | 298 | 84.42% | 2.770 | 3.240 | 3.128 | 3.236 | 2.885 |

Table 3 shows that most of the case study activities positively impacted URMs and their self-reported interest in comparison to non-URM students.

Table 4 reports the average Likert scores reported based on ethnicity for the first five questions on understanding in the engineering profession.

**Table 4: Ethnicity Based Self-Reported Understanding**

| Category | Count | % of total | Lectures | Grp. Act. | Ind. Res. | Projects | Readings |
|---|---|---|---|---|---|---|---|
| American Indian/Alaska Native | 1 | 0.28% | 3 | 3 | 3 | 3 | 3 |
| Asian | 20 | 5.67% | 3.4 | 3.8 | 3.75 | 3.55 | 3.5 |
| Black/African American | 18 | 5.10% | 3.611 | 3.444 | 3.667 | 3.611 | 3.5 |
| Foreign | 3 | 0.85% | 3.667 | 3 | 3.333 | 3 | 4 |
| Hispanic/Latino | 6 | 1.70% | 3.667 | 3.667 | 3.333 | 3.667 | 3.5 |
| Unknown | 7 | 1.98% | 3.571 | 3.571 | 3.714 | 3.143 | 3.571 |
| White | 298 | 84.42% | 3.419463 | 3.456376 | 3.510067 | 3.496644 | 3.353535 |

Table 4 shows that most of the case study activities positively impacted URMs and their self-reported understanding in comparison to non-URM students.

**Nonparametric Statistic Analysis – Mann-Whitney Test**

An additional statistical analysis performed on the 2009 data is based on the Mann-Whitney Test. The Mann-Whitney Test was used instead of a parametric method due to the differing N values for the interest questions (N=241 for White Males, and N=103 for URMs) and for the understanding questions (N=242 for White Males and N=104 for URMs). The discrepancy is based on two students not answering the first five questions on the survey. The unknown ethnicity individuals were also excluded from this analysis. The Mann-Whitney Test was performed ten times to allow comparisons of the answers for each question. Table 5 shows the test outcomes for the interest questions (1-5) and the test outcomes for the understanding questions (6-10). The null hypothesis ($H_0$) is that "Case study activity from question *I* does not affect the difference in the interest (or understanding) of the engineering profession by URMs compared to the control group (White Males). This null hypothesis is going to be rejected for significance values less than 0.10, meaning a 90% confidence interval for the differences in the medians.

**Table 5: Mann-Whitney Test N-values, Medians, Significance**

| Question | N-Value White Males | N-Value URMs | White Male Median | URMs Median | Significance |
|---|---|---|---|---|---|
| 1 | 241 | 103 | 3 | 3 | 0.2480 |
| 2 | 241 | 103 | 3 | 3 | 0.9434 |
| 3 | 241 | 103 | 3 | 3 | 0.2106 |
| 4 | 241 | 103 | 3 | 3 | 0.7560 |
| 5 | 241 | 103 | 3 | 3 | 0.0302 |
| 6 | 242 | 104 | 3 | 4 | 0.0483 |
| 7 | 242 | 104 | 3 | 4 | 0.1497 |
| 8 | 242 | 104 | 3 | 4 | 0.0931 |
| 9 | 242 | 104 | 3 | 4 | 0.1014 |
| 10 | 242 | 104 | 3 | 4 | 0.0508 |

Four of the questions distributions differed significantly (significance <=0.10) and there is one question that rounds to be equal to 0.10 from 0.1041. The questions that differed significantly were questions: 5 Reading and Supplemental Material impact on interest; 6 Classroom Lectures impact on understanding; 8 Independent Research impact on understanding; and 10 Reading and Supplemental Material impact on understanding. Question 9 has significance of 0.1041 which is very close to being significant. This significance can be used to show these case studies had a positive effect on the self-reported interest and understanding of the engineering profession by the URMs by invalidating the null hypothesis.

**Conclusions**

The summary statistics (averages > 3) indicate that students benefitted from the case study activities by increasing the students' interest and understanding of the engineering profession. By increasing the interest and understanding of the engineering profession, this should: 1. Broaden student understanding of the impact of engineering solutions in global and social contexts; and 2. Increase students' ability to apply knowledge of engineering to real life situations.

The nonparametric statistics (significance $\leq 0.1041$) show that underrepresented minorities (URMs) in engineering benefit from case studies and the activities associated with the exercises in their interest and understanding of the engineering profession.

Based on the information presented, case studies should require students to synthesize the facts and engineering principles they have learned, and combine them with their broader education in the arts, humanities, and sciences. Case studies also have the potential to further reach URM students that have difficulties relating to the engineering profession.

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