AC 2010-566: IMPLEMENTATION AND ASSESSMENT OF CASE STUDIES IN THE ENGINEERING CURRICULUM

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Implementation and Assessment of Failure Case Studies in the Engineering Curriculum: Work in Progress

Abstract:

The history of the development of practice in many engineering disciplines is, in large part, the story of failures, both imminent and actual, and of the changes to designs, standards and procedures made as the result of timely interventions or forensic analyses. In addition to technical issues, concepts such as professional and ethical responsibility are highlighted by failure cases. Pilot studies have been carried out over several semesters to assess the use of failure case studies in civil engineering and engineering mechanics courses at Cleveland State University under an earlier NSF project. Student learning has been assessed through surveys as well as focus groups, led by researchers from the Cleveland State University College of Education and Human Services. Students were asked specifically about the technical lessons learned, as well as their response to the case studies. Case study questions were included on homework assignments and examinations. Survey questions linked student achievement to learning outcomes. The focus groups identified additional benefits to the use of case studies. Students observed that the cases helped build engineering identity, and provided historical understanding. The cases made the technical information relevant and linked theory to practice. The project described in this paper will extend the work of implementing and assessing case studies from Cleveland State University to eleven other university partners, including using case studies in an Introduction to Engineering course for first year students, as well as the NSF Materials Digital Library for a total of thirteen universities participating in the project. The project is a work in progress, starting in the fall of 2009.

Introduction and Background

Lessons learned from failures have substantially affected the practice of civil engineering and other engineering disciplines. The history of development of practice in many engineering disciplines is, in large part, the story of failures and of the changes to standards and procedures made as the result of forensic analyses. In addition to technical issues, concepts such as professional and ethical responsibility are highlighted by failure cases.

Many authors over the past two decades have pointed out the need to integrate lessons learned from failure case studies in engineering education[1, 2, 3, 4, 5, 6, 7, 8, 9]. The case for including failure case studies in the engineering curriculum has been made by several authors, including Delatte and Rens[10], Delatte[11], Carper[8], Carper et al.[12], and Carper et al.[13]. 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 [10, 13]. 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*[14] refers on page 2 to textbooks lacking in practical examples as an emerging weakness. This source refers specifically to breadth of understanding, which may be achieved through case studies. Another issue addressed (14, 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*[15] proposes that as many undergraduate students as possible should undertake original, supervised research. *How People Learn*[16] page 30 refers to the need to organize knowledge meaningfully, in order to aid synthesis and develop expertise.

Pilot studies have been carried out over several semesters in order to assess the use of failure case studies in civil engineering and engineering mechanics courses at Cleveland State University (CSU). Student learning has been assessed through surveys as well as focus groups, led by researchers from the CSU College of Education and Human Services. The case studies were pilot tested in two courses, Strength of Materials (sophomore, engineering mechanics) and Construction Planning and Estimating (senior, civil engineering), in the spring 2007 and spring 2008 semesters.

Students were asked specifically about the technical lessons learned, as well as their response to the case studies. Case study questions were included on homework assignments and examinations. Survey questions linked student achievement to educational outcomes. The focus groups identified additional benefits to the use of case studies. The sophomore students observed that the cases helped build engineering identity, and provided historical understanding. The cases made the technical information relevant and linked theory to practice.

In addition, faculty who participated in the case study workshops have been surveyed about the time commitment required to implement the case studies, and whether the benefits justify the investment. Since teaching and revising a course is a time-consuming endeavor, faculty will only incorporate failure case studies if that can be done fairly easily, and if the benefits can be shown to be substantial. The faculty responses overwhelmingly agreed that the benefits justified the investment of time[17].

This project will extend the work from Cleveland State University to 11 other university partners as well as the Materials Digital Library. Especially interesting is the inclusion of a first year Introduction to Engineering course which used case studies to introduce the profession of engineering including ethical issues. Students were surveyed to assess the impact of case studies on their interest and understanding of engineering. This is a recently funded four year project. This paper reviews the background and rationale for the project, as well as the pilot study results and the work plan.

Project Objectives:

The objectives of this project will be to

- Assess the use of case studies in different programs and in different university settings, using the assessment materials developed at Cleveland State University. Data will be collected and analyzed at Cleveland State University.
- Collect aggregate data across the participating campuses from underrepresented groups in engineering, specifically women and minorities.
- Determine the ease of use and effectiveness of implementing case studies at different campuses
- Collect new case study information though the Materials Digital Library web site.
- Continue the annual Failure Case Study Faculty Workshop series, with a renewed focus on implementation and assessment, at the annual ASEE conference.
- Assess the impact of case studies on first year students, specifically analyzing the impact on women and minorities.

The Project Team

The members of the project team are prior attendees of the Faculty Failure Case Study workshops and have already been making use of failure case studies in their courses. The most extensive prior work has been carried out at Cleveland State University. The subcontractors are listed in Table 1.

Table 1: Participating Universities, Faculty, and Programs

University	**Faculty**	**Programs**
Cleveland State University	Norbert Delatte, Paul Bosela, Joshua Bagaka's	Civil Engineering, Engineering Mechanics
University of Wisconsin Platteville	Matt Roberts, Keith Thompson	Civil Engineering
University of Louisville	Patricia A Ralston, Donald J. Hagerty, Jim Lewis, Dave Wheatley	Engineering Fundamentals, Civil Engineering
Southern Polytechnic State University	Gouranga Banik	Construction Management
Case Western Reserve University	Xiong (Bill) Yu	Civil Engineering
Lamar University	Mark C. Bourland	Civil Engineering
Pennsylvania State University	Kevin Parfitt, Andrew Scanlon	Architectural Engineering, Civil Engineering
California State University, Fresno	Manoochehr Zoghi	Construction Management
University of North Carolina at Charlotte	Shen-en Chen	Civil Engineering
California Polytechnic State University	Pamalee Brady	Architectural Engineering
Colorado State University	Becki Atadero, Marvin Criswell	Civil Engineering
University of Alabama	Philip Johnson	Civil Engineering
Kent State University	Laura Bartolo	Materials Digital Library, Center for Materials Informatics, College of Arts & Sciences

Each of the 11 subcontractors (Kent State University excepted) will:

1. Use case studies in at least 2 courses during the subcontract period.
2. Collect student survey data for students participating in the courses and provide to Cleveland State University (CSU), using forms developed at CSU and modified during this project.
3. Collect student survey data from underrepresented groups in engineering, specifically women and minorities. Since few subcontractors, if any, have enough women and minorities in engineering to be statistically significant, aggregating the data will make it possible to determine overall trends.
4. Participate in faculty surveys during the project

5. Participate in at least one faculty focus group during the project.
6. Contribute at least one new case study to the case studies web site http://matdl.org/failurecases/

Intellectual Merit

The main intellectual merit of this project will be demonstrating the positive impact of case studies across a variety of universities and programs. The university partners in this project include public and private institutions, undergraduate-only programs and universities with doctoral programs, and programs in civil engineering, engineering mechanics, engineering fundamentals, architectural engineering, and construction management. Involving this broad range of universities and programs will help spread the word about the beneficial impacts of case studies. The surveys conducted will also verify and strengthen the argument for using case studies.

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 aspects, ethical issues, and procedural issues and require students to undertake higher order thinking in order to synthesize the relevant issues. The case study products of this research project will help civil engineering educators improve their teaching of specific technical topics within the discipline.

As an example, the learning framework of Professor Brady's application of case studies in a Steel Building Design Laboratory will employ the learning cycle instructional model. The three stages of exploration, concept introduction, concept application will be employed. Initial exploration is designed to engage and recall knowledge that is applicable to the new concept. Links are then drawn between the new concept and previous knowledge and the students explore this concept in detail in the second stage. Finally the students are asked to apply the concept information to a similar instance which extends their learning into still newer territory while building skills and confidence to face problems not previously encountered.

One application of this learning framework makes use of the Hartford Arena Roof Collapse Case Study. First, computer modeling techniques are recalled from the prerequisite structural analysis class. Techniques for checking computer analyses are discussed. The Hartford Arena case study is introduced and discussed. Students identify practices that would identify potential problems. This set enforces knowledge and comprehension, according to Bloom's taxonomy. Second, students are introduced to the analysis and design of Special Concentrically Steel Braced Frames. Behavior and modeling are discussed in detail. Computer data checks are established. This requires application and synthesis. Finally, behavior of Special Steel Moment Resisting Frames is discussed. Students are asked to set up computer models, analyze the frame and establish computer checks independently. Application, synthesis and evaluation are employed.

Failures are particularly valuable case studies for a number of reasons:

- They dramatically illustrate the consequences of poor engineering judgment and practices and errors (thus assisting the socialization process)
- They nearly always have an element of mystery – what happened, and why? (thus enhancing interest and intellectual engagement)
- They usually require students to "stretch" intellectually (thus showing the process of lifelong learning, and helping students become more active learners)

Other participants will similarly develop applications for case studies in engineering and construction management curriculum.

The Materials Digital Library

Faculty at Kent State University (KSU) have a very different role in this project. KSU is currently housing the project's web site, http://matdl.org/failurecases/, and will redesign the web site as a wiki. The following outlines MatDL's participation in the project.

MatDL Infrastructure

The online community for faculty and their materials failure case studies will be housed on the Materials Digital Library Pathway (MatDL http://matdl.org) in the MatDL Wiki (http://matdl.org/matdlwiki), an online space for community-based collaborative projects. A wiki is a kind of website that allows users to add, remove, or edit content, very quickly and easily. Wikis are considered to be a low-barrier, easily adoptable method of facilitating communication, collaboration, and content sharing[18, 19]. Through this proposal, the current functionalities of the MatDL Wiki, an online collaborative workspace, will be customized to support the specific education needs of this proposed materials failure case studies community of faculty, including distributed interdisciplinary collaboration. While the wiki will be publicly viewable, development of wiki content will be restricted to members of the failure cases project to ensure that the information is scientifically authoritative. Additionally, the individual digital resources (images, diagrams, reports, etc) developed from this proposal will be archived in the MatDL Repository (http://matdl.org/repository/) for dissemination and reuse.

MatDL currently serves as a Pathway in the National Science Digital Library (NSDL http://nsdl.org) to facilitate the integration of materials research and education. NSDL provides a dynamic, organized point of access to science, technology, engineering, and mathematics (STEM) education and research resources targeted at all audience levels as well as access to services and tools that enhance the use of this content in a variety of contexts[20]. NSDL includes ten Pathways each focused on particular domains, such as Biology, and audiences, such as middle school students. As part of the NSDL, the MatDL Pathway serves the materials research and education community for undergraduates and above[21]. NSDL and MatDL are committed to complying with standards and protocols, including Dublin Core Metadata Standard (http://dublincore.org/) and Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH; http://www.openarchives.org) to achieve better interoperability. NSDL and MatDL both employ OAI-PMH to make all of MatDL's metadata, including the resources resulting from this proposal, available in the NSDL National Digital Repository (NDR) to support broader dissemination and reuse of data across a range of users.

Adhering to open standards and open access protocols[22], MatDL leverages, implements and maintains current, recognized, community-centered software, such as wikis (Mediawiki), and content management systems (Fedora/Fez) to connect distributed teams and promote information sharing and dissemination. MatDL will be responsible for maintaining and upgrading the wiki and repository hardware and software as well as making customizations for the failure cases project. MatDL will migrate the contents of the current failure cases site (http://matdl.org/failurecases) into wiki format and will maintain backups of the data resulting from the failure cases project.

MatDL's collaboration tools, services, and systems to support the online community activities include:

MatDL's Wiki currently provides online workspace for distributed government and university team-based, materials projects using Mediawiki, to support coordinated collaborative writing and editing efforts. Mediawiki (http://www.mediawiki.org/wiki/MediaWiki) is free server-based software. Its wikitext format allows users without knowledge of XHTML or CSS to edit pages easily. MediaWiki maintains versioning on each page making it easy to track legitimate contributions. The incorporation of image and multimedia files into pages is also supported. Customized functionality, such as threaded discussion boards, will be added to MatDL Wiki to meet the needs of the proposed faculty network. Online help will be available to support creation and maintenance of the materials failure case studies wiki. Several different communication channels, such as a private threaded discussion board and calendar, will facilitate the interactions of the project team. A search plug-in to the MatDL Repository will be available from the MatDL Wiki project site to identify any relevant resources and research results that may be relevant to the case studies.

The ***MatDL Repository***, powered by Fedora/Fez, describes, stores, and disseminates individual digital resources submitted by faculty, researchers, and students in the materials community, such as lecture notes and problems, powerpoint presentations, images, and datasets. Fedora (http://www.fedora-commons.org/) is an open-source Flexible, Extensible, Digital Object Repository Architecture that supports the reuse and re-purposing of individual digital resources. Fez (http://dev-repo.library.uq.edu.au/wiki/) is open-source web front-end content management system for Fedora developed as part of the University of Queensland eScholarship Project and the Australian Partnership for Sustainable Repositories.

Expected Measurable Outcomes:

Outcomes in student achievement will be tied to the ABET, BOK1, and BOK2 criteria discussed earlier. These are measurable outcomes that the engineering community has already determined to be important.

Project Evaluation:

This project is strongly student focused – its importance and impact is on preparing engineering students to become better engineers. However, the assessment will focus first on faculty expertise, and second on student learning. Faculty expertise is an important first step because until faculty are able to extract full benefits from the case studies, it will be difficult to substantially enhance student learning. Desired student learning outcomes are:

1. Improved understanding of technical issues in civil engineering and engineering mechanics and related fields
2. Improved understanding of ethical, professional, and procedural issues in civil engineering and engineering mechanics
3. Improved understanding of the profession of engineering by first year students

These measurable outcomes may be used to monitor progress, guide the project, and evaluate its ultimate success. Assessment of a large and complex project of this nature represents a significant challenge. Therefore, the project team includes assessment expertise from the CSU College of Education and Human Resources. The primary assessment question is: "In what ways does the use of failure case studies improve students' ability to demonstrate competencies that prepare them to be better professional civil engineers?"

Assessment efforts will focus on student performance, attitudes towards the use of the case studies, faculty experience and cost/benefit factors (e.g., time to learn how to use the case study, value-added). The assessment will use *both direct and indirect measures* and every effort will be made to triangulate the methods chosen (both breadth and depth). Surveys, focus groups, interviews and classroom observations will be conducted for program assessment. Faculty will analyze the effect on student learning on those activities designed to capitalize on the demonstrated levels of learning that occur as a result of using case studies.

When possible, student performance will be compared to those students who are expected to have the same learning but are not using the case studies. This could be students in a different section of the same course, or students who are having the same pedagogical experience in different courses. Results will also be analyzed to see if there are differences in the study variables among students according to such factors as learning styles, academic standing, gender, ethnicity, and personality type preferences.

Evaluation will focus both on process and on product. The assessment of process will determine whether implementation followed the plan, and the assessment of product will evaluate whether the expected student learning outcomes were achieved.

The assessment questions are as follows:

- Does the use of failure case studies improve students' ability to demonstrate competencies that better prepare them as professional engineers for the 21st century?
- How does the implementation of failure case studies encourage deep learning in civil engineering students?
- What has been the time commitment and value-added experience for faculty who integrate failure case studies in the course curriculum that improves student learning of civil engineering concepts?

Specifically, assessment will consist of the following:

Preparation of Assessment Materials. Preparation of assessment materials will comprise a significant effort in the first year of the program. In order to permit implementation of pilot studies in year 1, early emphasis will be on the development of the materials to be used in each course (see below) and to be administered during faculty workshops (also see below). Development of assessment tools should be 75% complete by the end of year 1. Focus group scripts and faculty interviews will be developed during year 2 based on the information received from the first set of course surveys and class observations administered during year 1.

Pilot Studies. Program assessment should measure whether the desired learning occurs in pilot implementations in a diversity of classroom settings. The program will thus include pilot studies at CSU where the materials will be implemented in at least new one course each of the three years of the study.

1. Pre- and post-course surveys of students. Standard surveys will be developed by CSU College of Education and Human Resources researchers, administered by the course instructors, and interpreted by CSU College of Education and Human Resources personnel. Pre- and post-course surveys will be administered for each course offering, so a total of 20 pre/post surveys will be conducted. When possible, the surveys will also be administered to another group of students taking the same course but without benefit of the use of failure case studies. The surveys in the Introduction to Engineering course at the University of Louisville will be of particular interest.

2. Student focus groups. Focus groups are a highly useful means of assessment program success and for identifying areas for improvement. Scripts will be created for administration of focus group studies. Administration of focus group activities will be by personnel independent of the faculty instructor to assure students will provide both positive and negative insights. CSU College of Education and Human Resources researchers will interpret the focus group feedback provided by the focus groups.
3. Faculty interviews and surveys. CSU College of Education and Human Resources researchers will interview each of the faculty administering the pilot study courses to assess progress towards the program goals and objectives. In addition, CSU College of Education and Human Resources researchers will prepare and administer surveys of faculty participants to be used in conjunction with the program of workshops.

Perceived Impact of Workshops. The four proposed program workshops provide an opportunity to assess faculty participants' impressions of whether the workshop and materials will have or have had an impact on the learning in their courses. Surveys will be developed for faculty participants to complete prior to and immediately after each workshop. Each workshop will also feature a 30 minute roundtable to foster brainstorming and evolution of the program for continuous improvement. Follow-up surveys will be administered by email 12 months after the workshop for all workshops conducted. For the three workshops featuring 20 participants each, this constitutes 60 pre-workshop surveys, 60 end-of-workshop surveys, 3 roundtable discussions, and up to as many as 60 surveys administered 12 months after workshop completion.

Project Institutionalization: This innovation will be institutionalized at the participating colleges and universities.

Description of the Workshops

The ASCE TCFE workshops have focused on linking case studies to specific topics in one or more civil engineering or engineering mechanics courses. Case study presentations and reading assignments have been developed to build student knowledge, and these have been provided in the workshop materials. The workshop materials included copies of case study technical papers along with a CD of PowerPoint presentations on individual case studies.

The case studies may be used to introduce topics and stimulate classroom discussion. Students may be given specific homework examples and examination problems that require application of the case studies. These assignments can provide documentation that the specific outcomes have been met.

The workshop participants have been surveyed about how they are using case studies for pedagogical aims. Eighteen responses were received, and of those fourteen were using case studies some or a lot. All fourteen agreed that the benefits of using the case studies justified the necessary time and effort. Complete results are reported elsewhere[23].

Faculty Feedback from the Workshops

Faculty workshop participants from the 2003 through 2006 workshops were surveyed by email in January 2008. The workshop participants were primarily from U.S. civil engineering programs, but also included faculty in architectural, construction, and other engineering programs, and faculty from Canada and Ireland.

Survey questions and some of the responses are provided in Delatte et al.[23]. Eighteen surveys were returned, but only 14 of the respondents were using case studies. Since the email was sent to 54 past participants, it is likely that the surveys returned over-represented those faculty that are currently making use of case studies.

Most faculty who had participated in the one-day case study workshop and who responded to the survey had made at least some use of the cases in their courses. Although the range of responses was wide, responses indicated:

- It was not particularly difficult to include case studies in courses
- The workshop materials were helpful
- A significant time commitment was often needed to incorporate case studies
- Usefulness to students was high

All fourteen respondents that had used case studies believed that the benefits justified the cost, in terms of faculty time and effort. A number of them requested additional case study materials. Complete results are reported in Delatte et al. [23] including courses and students, barriers to implementation, and usefulness of the workshop materials.

Pilot Studies and Results

Results so far from student surveys and student focus groups indicate that the students believe that the case studies inspire them to learn, and help them understand the importance of non-technical issues in engineering practice. Student learning has been assessed through surveys as well as focus groups, led by researchers from the Cleveland State University College of Education and Human Services. The case studies were pilot tested in the spring of 2007 and spring 2008 in two courses, Strength of Materials (sophomore, engineering mechanics, ESC 211) and Construction Planning and Estimating (senior, civil engineering, CVE 403). The case studies were presented to the students through PowerPoint lectures, and technical papers were provided beforehand. The use of case studies in the Strength of Materials course was modified in a subsequent offering, based on the findings of this study.

Student Survey Results

Student survey responses from the two Spring 2008 courses are presented in tables 3 and 4[23]. Table 3 suggests which outcomes may be considered to be strongly supported by the failure case studies. The scale ranged from 1 – strongly disagree to 5 – strongly agree.

In 2007, the students in both classes rated ability to apply knowledge of mathematics, science, and engineering; understanding of professional and ethical responsibility; and knowledge of contemporary issues at 4 or higher on average. The sophomore students also rated the broad education necessary to understand the impact of engineering solutions in a global and social context above 4. The senior students rated ability to function on multi-disciplinary teams; ability to identify, formulate, and solve engineering problems; recognition of the need for, and an ability to engage in life-long learning; and ability to use the techniques, skills, and modern engineering tools necessary for engineering practice at 4 or higher. All average results were 3.33 or higher. This suggests that the failure case studies can be important for enhancing learning of all ABET outcomes.

With the 2008 results, shown in Table 3, the averages in both classes for ability to apply knowledge of mathematics, science, and engineering; understanding of professional and ethical responsibility; and knowledge of contemporary issues were all 3.81 or higher except for one value of 3.56. All averages were 3.50 or higher. Overall, these 2008 results are similar to the 2007 findings.

Table 3: Student Survey Responses related to ABET Outcomes (Spring 2008) [23]

	Strength of Materials ESC 211				Construction Planning and Estimating CVE 403			
The case studies contributed to:	Ave	SD	High	Low	Ave	SD	High	Low
my ability to apply knowledge of mathematics, science, and engineering;	3.89	0.89	5	2	3.81	0.54	5	3
my ability to design and conduct experiments, as well as to analyze and interpret data	3.56	0.75	5	2	3.81	0.40	4	3
my ability to design a system, component, or process to meet desired needs, using the principles of equilibrium;	3.80	0.87	5	2	3.94	0.77	5	3
my ability to function on multi-disciplinary teams	3.54	0.98	5	1	3.50	0.82	5	2
my ability to identify, formulate, and solve engineering problems;	4.19	0.57	5	3	3.88	0.72	5	3
my understanding of professional and ethical responsibility	4.52	0.70	5	3	4.88	0.34	5	4
my ability to communicate my problem solutions effectively;	3.85	0.91	5	2	4.00	0.73	5	3
the broad education necessary to understand the impact of engineering solutions in a global and social context	4.08	0.74	5	3	4.38	0.62	5	3
my recognition of the need for, and an ability to engage in life-long learning	4.16	0.69	5	3	4.63	0.50	5	4
my knowledge of contemporary issues	4.15	0.78	5	3	4.00	0.73	5	3
my ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	4.00	0.89	5	2	4.00	0.63	5	3

The students were also asked to rate the relative contributions of the textbook, lectures, homework, projects (if any), exams, and the case studies to their interest and understanding of the course material. In 2007, case studies were ranked at 4.33 (highest) and 3.88 (second highest) for interest by the sophomores and the seniors respectively, and at 4.0 for understanding (tied for third highest, highest). These show strong reinforcement of the specific course technical material. The 2008 results, shown in table 2, ranked case studies at 4.04 for sophomores and

4.50 for seniors for contribution to interest. These were the highest values. 2008 contributions to understanding were 3.73 for sophomores and 4.50 for seniors. The 2007 and 2008 results were roughly comparable.

Table 4: Student Survey Responses on Relative Contributions (Spring 2008) [23]

How well did each of these elements contribute to your INTEREST in the course material?								
Course	Strength of Materials ESC 211				Construction Planning and Estimating CVE 403			
	Ave	SD	High	Low	Ave	SD	High	Low
Textbook	3.00	1.13	5	1	3.00	1.00	4	1
Lectures	3.92	0.84	5	3	4.38	0.96	5	2
Homework	3.69	0.88	5	1	3.50	0.63	5	3
Projects	3.26	0.92	5	1	3.15	0.90	4	1
Exams	3.42	1.06	5	2	3.56	0.73	5	3
Cases	4.04	0.87	5	2	4.50	0.63	5	3
How well did each of these elements contribute to your UNDERSTANDING of the course material?								
Textbook	3.54	1.07	5	1	3.18	1.17	5	1
Lectures	4.08	0.74	5	3	4.50	0.89	5	2
Homework	4.00	0.85	5	2	4.13	0.81	5	2
Projects	3.09	0.95	5	1	3.18	1.54	5	1
Exams	3.54	1.14	5	2	3.88	0.72	5	3
Cases	3.73	0.87	5	2	4.50	0.63	5	3

The summary statistics indicate that students benefited most from case studies in the following ways:

1. Making the course more interesting.
2. Helping students broaden their understanding of the impact of engineering solutions in global and social contexts.
3. Making students aware of their professional and ethical responsibility.
4. Increasing students' ability to apply knowledge of engineering to real life situations.

Student Focus Group Results

Researchers from the CSU College of Education and Human Services discussed the use of the case studies in student focus groups without the instructors present, in both spring and fall 2007 and again in spring 2008. Summary results are provided in Delatte et al. [23].

During the focus groups, the students were asked specifically about the technical lessons learned, as well as their response to the case studies. Case study questions were included on homework assignments and examinations. Survey questions linked student achievement to the a–k ABET outcomes.

The focus groups identified additional benefits to the use of case studies. The sophomore students observed that the cases helped build engineering identity, and provided historical understanding. The cases made the technical information relevant and linked theory to practice.

Overall, the students remembered a lot about the case studies, including names, dates, and technical details.

Broader Impacts

This project has the strong potential for broad transformation of engineering education. The broader impacts of the project will be the demonstrating the implementation of a set of fully developed case studies for civil engineering education in a variety of university settings. Nineteen faculty members will be participating in this project at 12 different university sites, with a minimum of 24 courses offered incorporating the case studies. With a mean enrollment per course of 20 students, the project is expected to affect a total of 4,800 students. The work will also be disseminated through faculty workshops to another 80 to 100 faculty, which will have a larger but more indirect impact. The faculty alumni of the seven previous case study workshops have already benefited a large number of undergraduate students across the US and around the world.

Case studies also have the potential to reach students that 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 a lifetime of helping their parents with hands on projects[24]. 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 the case study is introduced and taught in the right way, it is possible that it could give these students 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 the family. When they try to 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 that in the Introduction to Engineering course taught by the Department of Engineering Fundamentals at the University of Louisville. Research has shown that first year students frequently leave engineering because they take courses that are math and science intensive, but they can't relate to the profession of engineering. Introduction to Engineering courses have attempted to stop this attrition by various methods, including hands-on projects and other activities. Case studies provide a unique way to address this without the purchase of expensive laboratory equipment needed for hands-on activities. They also provide an opportunity to talk about communication, team-work, ethics, and life-long learning.

Integrating Diversity into NSF Programs, Projects, and Activities

At present, women and minorities are underrepresented in civil engineering and other engineering disciplines. This has been identified as a problem of national importance[25]. The first author has been very successful at working with undergraduate women students to publish case study papers. However, at Cleveland State University, there have been too few women and minorities in the assessment pool to have a statistically significant sample.

With the expansion to eleven other university sites, however, there will be enough participants in the aggregate to determine if, in fact, the use of case studies has a measurable impact on the engagement and learning of women and minorities. At the University of Louisville site, for example, the case studies will be used in ENGR 100, which is required for all freshman engineering students. The course has 4 % minority students and 18 % female. One partner with high enrollment of women is the Architectural Engineering Program at Cal Poly, which has 40% women and thus provides an excellent opportunity for statistically significant sampling. It has been documented that attrition rates are higher for women in engineering[24].

This project will also investigate the modification 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 achievement and interest of underrepresented groups. Part of the work plan is to review and modify the existing case studies, and focus the development of new case studies, on crafting our stories to be of greater interest for underrepresented groups. This may also involve adding specific focus groups of these students at our larger sites.

Conclusions

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 aspects, ethical issues, and procedural issues and require students to undertake higher order thinking in order to synthesize the relevant issues. The case study products of this research project will help civil engineering educators improve their teaching of specific technical topics within the discipline.

The main intellectual merit of this project will be demonstrating the positive impact of case studies across a variety of universities and programs. The university partners in this project include public and private institutions, undergraduate-only programs and universities with doctoral programs, and programs in civil engineering, engineering mechanics, engineering fundamentals, architectural engineering, and construction management. Involving this broad range of universities and programs will help spread the word about the beneficial impacts of case studies. The surveys conducted will also verify and strengthen the argument for using case studies.

The broader impacts of the proposed activity will be the implementation of a set of fully developed case studies for civil engineering education. The work will also be disseminated through faculty workshops to other faculty, which will have a larger but more indirect impact. Case studies also have the potential to reach students which have difficulties relating to the engineering profession.

The results of the pilot study so far, at Cleveland State University, have been highly encouraging. It is anticipated that this expanding the work to other universities will provide further insight into the educational benefits of case studies.

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References

[1] Bosela, P. A. (1993). "Failure of Engineered Facilities: Academia Responds to the Challenge," J. Perf. Const. Fac., ASCE, 7(2), 140-144.

[2] Rendon-Herrero, O. (1993a), "Too Many Failures: What Can Education Do?" J. Perf. Const. Fac., ASCE, 7(2), 133-139.

[3] Rendon-Herrero, O. (1993b), "Including Failure Case Studies in Civil Engineering Courses," J. Perf. Const. Fac., ASCE, 7(3), 181-185.

[4] Baer, R. J. (1996). "Are Civil Engineering Graduates Adequately Informed on Failure? A Practitioner's View," J. Perf. Const. Fac., ASCE, 10(2), 46.

[5] Delatte, N. J. (1997). "Failure Case Studies and Engineering Ethics in Engineering Mechanics Courses," J. Profl. Issues in Engrg. Education and Practice, ASCE, 123(3), 111-116.

[6] Rens, K. L., and Knott, A. W. (1997). "Teaching Experiences, a Graduate Course in Condition Assessment and Forensic Engineering." Forensic Engineering: Proceedings of the First Congress, K. L. Rens, ed., ASCE. New York, N. Y. 178-185.

[7] Pietroforte, R. (1998). "Civil Engineering Education Through Case Studies of Failures," J. Perf. Const. Fac., ASCE, 12(2), 51-55.

[8] Carper, K.L. (2000). Lessons from failures: case studies as an integral component of the civil engineering curriculum, *Civil and structural engineering education in the 21st century*, Southampton, UK.

[9] Rens, K L., Rendon-Herrero, O. and Clark, M.J. (2000): "Failure Awareness of Constructed Facilities in the Civil Engineering Curriculum," *Journal of Performance of Constructed Facilities*, Volume 15, No. 1. pp 27-37.

[10] Delatte, N.J., and Rens, K. L. (2002), "Forensics and Case Studies in Civil Engineering Education: State-of-the-Art," *ASCE Journal of Performance of Constructed Facilities,* Vol. 16, No. 3, August, 2002

[11] Delatte, N.J. (2006) "Learning from Failures," *Civil Engineering Practice,* Journal of the Boston Society of Civil Engineers Section/ASCE, Vol. 21, No. 2, pp. 21 – 38, Boston, MA, Fall/Winter 2006.

[12] Carper, K.L., Delatte, N.J. and Rens, K. (2007). Lessons from failure investigations: a resource for engineering education, *Proceedings of the 2007 International Conference on Forensic Engineering*, India Chapter of American Concrete Institute (ICACI), Mumbai, India.

[13] Carper, K.L., Delatte, N.J., and Bosela, P.A. (2008) Status of forensic engineering education in the United States, *Proceedings of the fourth international forensic engineering conference: from failure to understanding*, 2-4 December 2008, London, UK.

[14] Center for Science, Mathematics, and Engineering Education, National Research Council (1996). *From Analysis to Action.* National Academy Press, Washington, D.C.

[15] Committee on Undergraduate Science Education, *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology,* Center for Science, Mathematics, and Engineering Education, National Research Council, 1999.

[16] Bransford, J. D., Brown, A. L., and Cocking, R. L., (1999), *How People Learn: Brain, Mind, Experience, and School,* National Academy Press, Washington, D.C.

[17] Norbert J. Delatte, Paul A. Bosela, Rosemary Sutton, Joshua Bagaka's, *Implementing Forensics and Failures in the Civil Engineering Curriculum,* Proceedings of the Fourth International Conference on Forensic Engineering – From Failure to Understanding, London, UK, December 2, 2008.

[18] Frumkin, J. (2005). The wiki and the digital library. *OCLC Systems & Services: International Digital Library Perspectives, 21*(1), 18-22.

[19] Fichter, D. (2005). Intranets, wikis, blikis, and collaborative working. *Online, 29*(5), 47-50.

[20] Zia, L. L. (2002, November). The NSF National Science, Technology, Engineering, and Mathematics Education Digital Library (NSDL) Program. *D-Lib Magazine, 8* (11). Available at: http://www.dlib.org/dlib/november02/zia/11zia.html

[21] Bartolo, L.M., Glotzer, S.C., Lowe, C.S., Powell, A.C., Sadoway, D.R., Warren, J.A., Tewary, V.K. and Rajan, K. (2006). NSF NSDL Materials Digital Library & MSE education. *Journal of Materials Education, 28* (1), 21-26.

[22] Hannay, T. (2007, August). Web 2.0 in science. *CTWatch Quarterly, 3* (3). Available at: http://www.ctwatch.org/quarterly/articles/2007/08/web-20-in-science/

[23] Delatte, N., Bosela, P., Sutton, R., Beasley, W., and Bagaka's, J. (2008) "Assessing the Impact of Case Studies on the Civil Engineering and Engineering Mechanics Curriculum," *Proceedings of the 2008 American Society for Engineering Education Annual Conference & Exposition,* Pittsburgh, PA, 22 – 25 June 2008.

[24] Henes, R., Bland, M., Darby, J., McDonald, K. (1995), "Improving the Academic Environment for Women Engineering Students Through Faculty Workshops," *Journal of Engineering Education,* pp. 59 – 67, January 1995.

[25] Leslie, L.L., McClure, G.T., and Oaxaca, R.L. (1998) "Women and Minorities in Science and Engineering: A Life Sequence Analysis, The Journal of Higher Education, Vol. 69, No. 3 (May – June 1998, pp. 239 – 276).