



Results from Implementation and Assessment of Case Studies in the Engineering Curriculum

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Lessons learned from case studies have had a significant impact on both education and practice of engineering and related disciplines. The history of practice in many engineering disciplines is, in large part, the story of failures, both imminent and actual, and ensuing changes to designs, standards and procedures made as the result of timely interventions or forensic analyses. In addition to technical issues, professional and ethical responsibilities are highlighted by the relevant cases. Student learning was assessed through surveys and focus group discussions. 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. Over the past few years the project extended the work of implementing and assessing case studies from Cleveland State University to eleven other university partners, and broadened the scope to cover multiple engineering disciplines, as well as the NSF Materials Digital Library. This paper reports on the results from including case studies in various courses at a diverse data set of universities. The results strongly suggest that failure case studies support a subset of ABET outcomes that may be referred to as the “Professional Component” of the curriculum. The Professional Component outcomes include understanding of professional and ethical responsibility, understanding the impact of engineering solution, life-long learning, and knowledge of contemporary issues.

Background and Introduction

This paper continues reporting on a research project being carried out by twelve universities with National Science Foundation (NSF) funding. At these universities, failure case studies were integrated into existing courses. Lessons learned from case studies have had a significant impact on both education and practice of engineering and related disciplines. The history of practice in many engineering disciplines is, in large part, the story of failures, both imminent and actual, and ensuing changes to designs, standards and procedures made as the result of timely interventions or forensic analyses. In addition to technical issues, professional and ethical responsibilities are highlighted by the relevant cases. More details about this research project are provided elsewhere ¹.

This was a broad project with many aspects. It built on prior work developing failure case studies for incorporation into engineering courses, with specific application to civil engineering, engineering mechanics, architectural engineering, civil engineering technology, and construction management.

Failure case studies may be used in engineering courses to address technical topics as well as non-technical topics, such as management, ethics, and professionalism. The authors have developed a number of failure case studies for classroom use. 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.

Each partnering university gathered student survey data about the impacts of including failure case studies in courses. At the lead university, Cleveland State University, the surveys were

supplemented by focus groups in several courses in civil engineering and engineering mechanics. Faculty at the partnering universities were surveyed about their experiences in using failure case studies in their courses.

These efforts have been supplemented by other activities. These included the project web site and a series of faculty workshops.

Student Surveys and Results

Students in courses were surveyed about the contribution of failure case studies to attainment of the ABET Criterion 3 a-k student outcomes². The students were also surveyed about how failure case studies contributed to their interest in and understanding of course material. 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.

When the survey results were analyzed, it was found that the 11 student outcomes could be sorted into two categories, Technical Component and Professional Component³. The ABET student outcomes grouped under the “Technical Component” refer to the application and analysis skills in engineering. Specifically, these are:

- (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
- (e) an ability to identify, formulate, and solve engineering problems
- (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The student outcomes grouped under the professional component address non-technical competencies that are vital to engineering practice. These are:

- (d) an ability to function on multidisciplinary teams
- (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.

It was originally hypothesized that the results of assessment of the technical component would be most important and interesting. However, as the project proceeded, it was recognized that the results of assessing the technical component might be more valuable. This is because it is often more difficult to document attainment of these student outcomes than to assess the technical component. Furthermore, while it is generally a relatively simple matter to incorporate technical outcomes into course material, it is often more challenging to address professional issues.

Over the course of several years, student survey data were gathered from multiple universities, most of which used cases in multiple courses. A total of 718 student responses from seven universities was analyzed. The analysis of the student survey data was completed in 2013 and

has already been reported in detail. This reference also includes a copy of the survey instrument as an appendix.⁴

“The results from multiple universities and multiple course offerings demonstrate that failure case studies can be used to provide indirect, quantitative assessment of multiple student learning objectives. Several outcomes that constitute the professional component of the curriculum may be assessed in this way.”

“The strongest results were for student outcomes (f) an understanding of professional and ethical responsibility, (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, and (j) a knowledge of contemporary issues. Although student outcomes (d), an ability to function on multidisciplinary teams, and (g), an ability to communicate effectively also generated reasonable results, it would probably be more effective to assess these particular outcomes elsewhere within the curriculum.”⁴

Student Focus Groups and Results

A series of student focus groups were conducted over a four-year period in multiple engineering classes at Cleveland State University, where failure case studies were discussed. The focus group guiding questions were selected in order to allow students in these courses to provide their views of the effectiveness of inclusion of case studies in the course. In order to ensure openness in students' discussions, these focus groups were conducted independently at the absence of the course instructor. The focus groups covered one course in engineering mechanics and multiple junior and senior level courses in civil engineering.

A wide range of suggestions and recommendations emerged from the students focus groups with regard to how inclusion of case studies would be made more effective. They included:

- Creation of a separate class that focuses on Failure Cases Studies, perhaps as an elective, would allow for an increased number of case studies covered. Such a course is offered as an elective at Pennsylvania State University.
- Instructors should select cases that span over a wider period of time (old ones as well as recent ones) in order to assess trends against policy changes.
- Students would like case studies that resulted from computer-design failures to be reviewed as well, especially given the fact that, of late, a number of procedures are highly computerized. The Hartford Civic Center represents an example of such a case⁸.
- It would be best if case studies were integrated with the other course content. An example was given of how the Pittsburgh case was well integrated throughout the ESC 211 Strength of Materials course.
- Attempts should be made to illustrate, using graphical representation of cases as they actually occurred. Most the case studies were helpful, and having pictures or video clips would be even more helpful.
- It would be beneficial to discuss and review success as well as the failure cases.
- Provide students with opportunities to go on field-trips, to see where and how some failure cases occurred.

- If possible have a guest speaker to come in and speak about having to work on a failure. Guest speakers are an important part of the elective course at Pennsylvania State University.

Other Activities

A number of failure case study materials had been developed under previous NSF projects⁵. Under this project, additional case studies were developed at Cleveland State University and at the other partnering universities, and disseminated through MATDL and faculty workshops discussed below.

NSF Materials Digital Library Web Site MATDL

One important product of this work has been a web site through the NSF Materials Digital Library entitled *Failure Case Studies: Civil Engineering and Engineering Mechanics*⁶.

Pennsylvania State University, one of the project subcontractors, has also developed a case studies failures wiki web site associated with its elective course on forensics and failures⁷.

Workshops

The research group has also led faculty development workshops over the course of a decade to promote the integration of failure case studies into engineering education. These have been funded by NSF and the American Society of Civil Engineers (ASCE). Workshops were originally held on university campuses, and later switched to the ASEE annual meeting and other venues. Workshop locations were Birmingham 2003 (University of Alabama at Birmingham), Cleveland 2004, 2005, 2006 (Cleveland State University), Denver 2007 (University of Colorado – Denver), ASEE Annual Convention Pittsburgh, PA 2008, ASEE Annual Convention Austin, TX, 2009, ASEE Annual Convention Louisville, KY, 2010, ASEE Annual Convention Atlanta, GA, 2013, and the National Building Museum, Washington, D.C., 2013.

Initially, the workshops focused on providing faculty with failure case study materials. Subsequently, as the research project has continued, the focus has shifted to discussing how to use the materials in the classroom and how to assess the impacts. Workshop participants are provided with a CD of case study PowerPoint presentations, which can also be made available through a Dropbox folder. Depending on budget constraints, participants have also been provided with a copy of *Beyond Failure*⁸. The Materials Digital Library also provides an important resource for workshop participants⁶.

In addition to the U.S. workshops, some members of the project team and colleagues were invited to give international forensic workshops. These included:

- Forensic Engineering Education Workshop, Taller de Ingenieria Forense para profesores de Ingenieria, hosted by the Instituto Tecnologica de Costa Rica, Cartago, Costa Rica, July 23 – 24, 2009
- Series of Workshops in China, with ASCE TCFE Delegation, March 11 – 24, 2010
 - First China-US Workshop on Safety and Forensic Practice of Civil Works, Shandong University, Jinan, Peoples' Republic of China, March 14 – 15, 2010

- US-Sino Transportation & Forensic Engineering Workshop, Zhejiang University, Hangzhou, Peoples' Republic of China, March 18 – 19, 2010
- First China-US Workshop on Forensic Practice and Stabilization of Civil Works, Hohai University, Nanjing, Peoples' Republic of China, March 21, 2011
- First India – U.S. Forensic Engineering Workshop, NIT Trichy, Tiruchirappally, Tamil Nadu, India, December 2010
- Two day Forensic Engineering workshop in Guayaquil, Ecuador, January 7 – 8, 2011, sponsored by Ecuador Group of ASCE

The international workshops demonstrated the broad appeal and interest of incorporating failure case studies and forensics in engineering education. Further details of these workshops are provided in another paper⁹.

Faculty Surveys

Faculty members from several universities who had incorporated failure case studies in their teaching in a variety of engineering courses were contacted by e-mail to comment on their perceived effectiveness of incorporating such case studies in their teaching. Complete detailed results are provided in another paper¹⁰.

There have traditionally been two important barriers to the incorporation of failure case studies into courses. The first obstacle has been a lack of available case study materials. These have largely been remedied through the two web sites and the book developed under this project and under earlier work by members of the research team^{6, 7, 8}.

The other barrier is the perception that it is time consuming and difficult to work cases into a course. All faculty participants in this survey indicated that incorporating failure case studies in the teaching was very helpful and inclusion of such case studies did not raise issues or cause problems in the courses they taught. Other than concerns for lack of time to effectively integrate failure case studies into the course materials, without displacing other course content, faculty participants did not express any difficulties in including failure case studies in the courses.

The amount of time spent discussing failure case studies varied. Some spent as little as 20 minutes while others reported spending as much as 7 class periods, but a range of 4-5 hours per semester seemed typical. The time it took to prepare for case studies did not seem to be a problem. Several faculty members indicated that it took minimal time to prepare and others estimated it to be 1-2 hours per case. Moreover, several participants indicated that, though it initially takes time to prepare, the time of preparation reduces substantially with the repeated use of case studies.

Summary and Conclusions

The assessment instruments and processes developed during the project have yielded some useful results. The results have held across multiple universities, as well as different types of programs and courses. The results for the professional (non-technical) component of the engineering curriculum have been particularly encouraging.

The student focus group results indicate students enjoyed the case studies and believed that they contributed to learning the course material. The case studies stimulated their interest. Perhaps more importantly, the focus group results show important impacts in terms of students' attitudes about their profession and about their responsibilities as engineers.

The web materials and other resources developed over the course of the project have made it much easier for other programs to include failure case studies in courses. The faculty workshops have been valuable for disseminating these materials, as well as demonstrating how best to use them and how to document their impact.

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⁶ Failure Case Studies: Civil Engineering and Engineering Mechanics, http://matdl.org/failurecases/Main_Page

⁷ Failures Wiki: Building, Architectural and Civil Engineering Failures and Forensic Practices, <http://failures.wikispaces.com/>

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