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

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Abstract

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. Pilot studies had assessed the use of failure case studies in civil engineering and engineering mechanics courses at Cleveland State University under an earlier NSF sponsored project. Over the past few years, the project has extended the work of implementing and assessing case studies from Cleveland State University to other university partners, and has broadened the scope to cover other engineering disciplines, as well as the NSF Materials Digital Library. This paper reports the results of case studies in various courses at a diverse data set from seven 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 responsibilities, understanding the impact of engineering solutions, life-long learning, and knowledge of contemporary issues.

Introduction

While the significance of students' exposure to failure case studies has been well documented,[1] the documentation of their relative benefits on different aspects of student learning outcomes (professional, technical, ethical, etc.) is scarce. The purpose of this study is to assess the impact of including case studies in civil engineering, engineering mechanics and construction management courses on students' technical and professional development. Existing and new failure case studies are being included in multiple undergraduate courses offered across a number of semesters at seven participating universities[1] (see Table 1).

In earlier work, students in courses were surveyed about the contribution of failure case studies to attainment of the ABET Criterion 3 a-k student outcomes[2]. A mixed-method of data analysis using both quantitative and qualitative approaches was used to determine the extent to which usage of case studies can impact different aspects of student growth. For the quantitative data, factor analysis with VARMAX rotation with Crombach Alpha reliability was used to identify dimensions of students' growth. It was found that the 11 student outcomes could be sorted into two categories, Technical Component and Professional Component[1].

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[2].

Table 1 – Summary of Participating Universities

Institution	Type	Program	Case Studies Used	In Courses (Sections)
Cleveland State University	Public Research	Civil Engineering	Quebec Bridge Silver Bridge/Point Pleasant Bridge Montreal Olympics Skyline Plaza/Bailey's Crossroads Harbour Cay Condominium	5 (12) n=195
University of Wisconsin – Platteville	Public Under-graduate	Civil Engineering	Quebec Bridge Hyatt Regency Walkway Sleipner A Offshore Platform Northridge, CA Earthquake Murrah Building 2001 Pentagon Attack	4 (15) n=354
University of North Carolina Charlotte	Public Research	Civil Engineering Technology and Construction Management	I-35W bridge collapse World Trade Center collapse Hyatt Regency Walkway Tacoma Narrows Bridge St. Francis Dam Failure	1 (1) n=70
Colorado State University	Public Research	Civil Engineering	Various Cases	1 (1) n=53
California State University, Fresno	Public Regional	Construction Management	Electrical Vault Failure on the Campus of Fresno State	1 (3) n=89
University of Alabama	Public Research	Civil Engineering	Various Cases	1 (1) n=26
Pennsylvania State University	Public Research	Architectural Engineering	Various Cases	1 (1) n=18

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[2].

This paper will focus on the use of failure case studies to address the professional component of the curriculum. This is because while assessing the degree of attainment of the technical component is relatively easy to assess through fundamentals of engineering exam results, coursework, and other means, it may be more challenging to assess the professional component.

Student Surveys

Each semester, participating students respond to a survey designed to assess the extent to which failure case studies in the curriculum contribute to students' knowledge, abilities, and interests in the course. Examples of results from individual courses have been previously published. At Cleveland State University, focus groups were also held in each course, and results from focus groups were previously reported. It was not possible to hold focus groups at the other universities[3].

Students were surveyed as to whether the inclusion of failure case studies helped them to attain outcomes. The survey instrument is provided in the appendix to this paper. They were asked: "Please rate the following with respect to your overall perception of the use of failure case studies in this class." Response options were based on a Likert scale: 1 – Strongly Disagree, 2 – Disagree, 3 – Neutral, 4 – Agree, 5 – Strongly Agree.

Participating Universities and Courses

Data from 718 student responses collected at the seven universities are analyzed and reported in this manuscript. At two of the universities, Cleveland State University and University of Wisconsin – Platteville, failure case studies had been used by at least two different instructors, in four or five different courses, over multiple years.

Cleveland State University is a public urban university that offers a Bachelor of Civil Engineering degree. Table 2 provides the Likert-scale averages of responses from students at Cleveland State University to the ABET professional components. There were a total of 195 student responses from Cleveland State University. Students from five different courses and a total of 12 class sections were surveyed. The course descriptions are provided below.

Table 2 – Results from Cleveland State University

Course and Semester	D Multidisciplinary teams	F Prof + Ethical	G Communicate	H Impact	I Lifelong Learning	J Contemporary issues
ESC 211						
2007	3.33	4.33	3.56	4.22	3.67	4.00
2008	3.54	4.52	3.85	4.08	4.16	4.15
2011	3.80	4.00	3.76	4.06	4.06	4.06
CVE 312						
2009	3.36	4.45	3.73	4.09	4.27	4.09
CVE 322						
2012	3.53	4.68	4.11	4.26	4.53	4.47
CVE 403						
2007	4.00	4.75	3.88	3.75	4.25	4.00
2008	3.50	4.88	4.00	4.38	4.63	4.00
2011	4.20	4.80	4.30	4.60	4.60	4.70
2012	3.82	4.82	4.18	4.41	4.76	4.53
CVE 422						
2009	3.20	4.73	3.47	4.00	4.13	4.07
2010	3.71	4.64	3.86	4.29	4.43	4.43
2012	3.77	4.78	4.34	4.59	4.72	4.66

- ESC 211 Strength of Materials. Study of stress, strain and stress-strain relations; stress-load and load-deformation relationships for axial, torsion and bending members; buckling of columns; combined stresses, inelastic behavior.

- CVE 312 Structural Analysis 1. Truss and frame analysis, influence lines and load position criteria, deflection analysis, analysis of indeterminate structures by compatibility methods, moment distribution method, slope deflection method.

- CVE 403 Construction Planning and Principles of Estimating. Types and uses of construction equipment and study of construction procedures; study of different types of estimates, direct and indirect costs, insurance, taxes, and bonds; analysis of construction schedule planning by CPM or PERT.

- CVE 322 Structural Steel Design. Design of structural steel components subject to tensile, compressive, bending and combined bending and compressive loadings; design of bolted and welded connections.

- CVE 422 Reinforced Concrete Design. Analysis and design of reinforced concrete members by service and ultimate strength methods; flexure, shear, displacement, and anchorage of beams; combined axial and bending stresses in columns; one-way slabs and continuous beams.

All of these courses are required for the Bachelor of Civil Engineering degree. Some examples of failure case studies used in courses at Cleveland State University include the Quebec Bridge collapse[4] (ESC 211), Silver Bridge/ Point Pleasant Bridge collapse (ESC 211), project management failure of the Montreal Olympics[5] (CVE 403), and the Skyline Plaza/ Bailey's Crossroads[6], Harbour Cay Condominium, and Laval, Quebec Bridge collapses[7].

University of Wisconsin – Platteville is also a public university offering a Bachelor's degree in civil engineering. Table 3 provides the averages, by course, from University of Wisconsin – Platteville based on a total of 354 student responses. Students from four different courses in 15 different sections were surveyed. The course descriptions are provided below.

Table 3 – Results from University of Wisconsin – Platteville

Course and Semester	D Multidisciplinary teams	F Prof + Ethical	G Communicate	H Impact	I Lifelong Learning	J Contemporary issues
GE 2130						
S 2010	3.85	3.81	4.27	3.88	3.85	3.46
F 2010	3.50	4.00	4.21	4.14	4.00	3.93
CE 3100						
F 2009	3.53	4.00	3.93	4.21	4.13	3.67
S 2010	4.04	4.00	4.17	3.96	4.25	3.83
F 2010	3.50	3.65	3.69	3.85	3.62	3.42
S 2011 s1	3.45	4.07	3.93	3.72	4.00	3.72
S 2011 s2	3.60	4.08	4.20	4.16	3.96	3.64
F 2011	3.74	4.04	4.04	3.89	4.15	4.00
S 2012	3.60	3.90	4.10	3.95	4.25	3.78
CE 3150						
F 2009	3.89	3.67	3.89	3.56	4.11	3.56
S 2010	4.15	4.00	3.85	3.92	4.08	3.77
F 2010	3.71	3.64	4.07	3.86	3.86	3.86
F 2011	3.94	4.24	4.06	4.20	4.31	4.29
S 2012	4.05	3.85	3.85	3.85	3.80	3.84
CE 4250						
F 2011	3.83	3.78	3.91	3.70	3.91	3.52

- GE 2130 Engineering Mechanics-Statics. Composition, resolution and equilibrium of forces and force systems; analysis of structures; friction; centroids; moment of inertia.

- CE 3100 Structural Mechanics. Design loads; stability and determinacy of trusses, beams and frames; member forces and deflection of statically determinate trusses; shear and moment diagrams, slopes and deflections of statically determinate beams and frames; influence lines and moving loads; force methods of indeterminate trusses, beams and frames; displacement methods of indeterminate beams and frames; approximate methods of indeterminate structures; computers in structural analysis. This is essentially the same course as CVE 312 at Cleveland State University.

- CE 3150 Reinforced Concrete Design. Design of reinforced concrete flexural members with consideration of shear, torsion deflection, and excessive cracking. Design of short compression members. Computer analysis of statically indeterminate structures; introduction to pre-stressed concrete and composite construction. This is essentially the same course as CVE 422 at Cleveland State University.

- CE 4250 Wood Structures. Anisotropic properties of wood; wood connectors; solid wood members; beams, columns and beam columns; plywood; glulam beams and arches; integrated design project.

Some examples of failure case studies used in courses at University of Wisconsin – Platteville include the Hyatt Regency Walkways collapse, the Sleipner A offshore platform sinking, the Quebec bridge collapse[4], failures during the Northridge, California earthquake, and the attacks on the Oklahoma City Murrah Federal Building and the Pentagon.

Table 4 summarizes the responses from the students at Cleveland State University and University of Wisconsin – Platteville. The table provides the overall mean and standard deviation of all 195 and 354 responses, respectively, as well as the high and low averages by course. The standard deviation values are all similar, ranging between 0.69 and 0.80, for a coefficient of variation range from approximately 17 to 25 %.

Table 4 – Summary Statistics from Cleveland State University and University of Wisconsin – Platteville

University	D Multidisciplinary teams	F Prof + Ethical	G Communicate	H Impact	I Lifelong Learning	J Contemporary issues
Cleveland State University						
Average	3.60	4.63	3.96	4.26	4.40	4.30
Standard Deviation	0.80	0.64	0.80	0.71	0.73	0.70
High	4.20	4.88	4.34	4.60	4.76	4.70
Low	3.20	4.00	3.47	3.75	3.67	4.00
University of Wisconsin – Platteville						
Average	3.75	3.95	4.03	3.94	4.03	3.79
Standard Deviation	0.77	0.74	0.69	0.71	0.73	0.74
High	4.15	4.24	4.27	4.21	4.31	4.29
Low	3.45	3.64	3.69	3.56	3.62	3.42

Table 5 provides responses from the University of North Carolina Charlotte, Colorado State University, and California State University Fresno.

Table 5 – Results from University of North Carolina Charlotte, Colorado State University, and California State University Fresno

University	D Multidisciplinary teams	F Prof + Ethical	G Communicate	H Impact	I Lifelong Learning	J Contemporary issues
University of North Carolina Charlotte						
2009	3.97	4.36	4.01	4.17	4.27	4.07
Colorado State University						
	3.43	3.57	3.96	3.74	3.94	3.36
California State University Fresno						
F 2009	4.10	4.59	3.95			
S 2010	4.26	4.57	4.04			
S 2011	4.74	4.67	4.19			

At University of North Carolina Charlotte, the course ETCE 3163L is required for the bachelor's degree in civil engineering technology, as well as the bachelor's degree in construction management. There were 70 student responses from this course. The course description is:

- ETCE 3163L. Structures and Materials Laboratory. Laboratory designed to evaluate structural materials commonly encountered in the civil and construction environments. Basic beam, truss and frame experiments will be conducted. Standard laboratory and field tests for typical materials such as block, brick, asphalt, concrete, steel and timber will be performed.

At Colorado State University, the CIVE 466 course is required for the bachelor's degree in civil engineering. There were 53 student responses. The course description is:

- CIVE 466 – Design and Behavior of Steel Structures. Loads acting on a structure; behavior and design of steel members, connections, and systems. This is essentially the same course as CVE 322 at Cleveland State University.

In contrast, California State University Fresno offers a bachelor's degree in construction management. There were 89 student responses from the CM 1S course. The course description is:

- CM 1S Construction Management Orientation Seminar. Orientation to essential elements of professional practice in construction management: construction-related regulatory requirements; ethics, business, safety, leadership, and personnel practices. Management techniques and interaction with professional organizations and associations.

The courses offered at University of Alabama and Pennsylvania State University were small enrollment electives specializing in forensic engineering. There were 26 student responses from University of Alabama and 18 from Pennsylvania State University (see Table 6).

Table 6 – Results from University of Alabama and Penn State University

University	D Multidisciplinary teams	F Prof + Ethical	G Communicate	H Impact	I Lifelong Learning	J Contemporary issues
University of Alabama						
	4.25	4.69	4.31	4.27	4.50	4.23
Pennsylvania State University						
	4.15	4.78	4.22	4.18	4.44	4.11

- The course at University of Alabama was CE 480 (Forensic Engineering). When failures in the built environment occur, whether during design, construction or in-service, a thorough examination of the causes is essential to both the evolution sound engineering practices and to dispute resolution through the legal system. The role of the engineer in this process is examined.

- The course at Pennsylvania State University was similar, and was listed as AE 537 Building Performance Failures and Forensic Techniques. This course provides a background in identification, evaluation, and analysis of a broad set of architectural and structural performance failures.

A summary of results for all participating Universities is shown in Figure 1. The error bars are only shown for Cleveland State University and the University of Wisconsin – Platteville because the other institutions had relatively small sample sizes.

Discussion

ABET defines assessment as "one or more processes that identify, collect, and prepare data to evaluate the attainment of student outcomes. Effective assessment uses relevant direct, indirect, quantitative and qualitative measures as appropriate to the outcome being measured."[2]

The survey results discussed in this paper, therefore, represent indirect quantitative measures that may be used to assess specific outcomes. In reviewing the results overall, it is clear that some of the professional component outcomes can be addressed more readily with failure case studies than others. Summary results by outcome are:

- Student outcome (d) an ability to function on multidisciplinary teams – overall, the results for this outcome were relatively low, with average values of 3.60 and 3.75 at Cleveland State University and University of Wisconsin – Platteville, respectively, with the highest section average of 4.15. It is likely that the students were not asked to function on a team in those classes. Results from other universities were similar, although there were some higher values reported by universities California State University Fresno and University of Alabama. This suggests that students have difficulty seeing the relationship between failure case studies and this student outcome, and a

course would likely require a group project or paper component in order to better address this outcome.

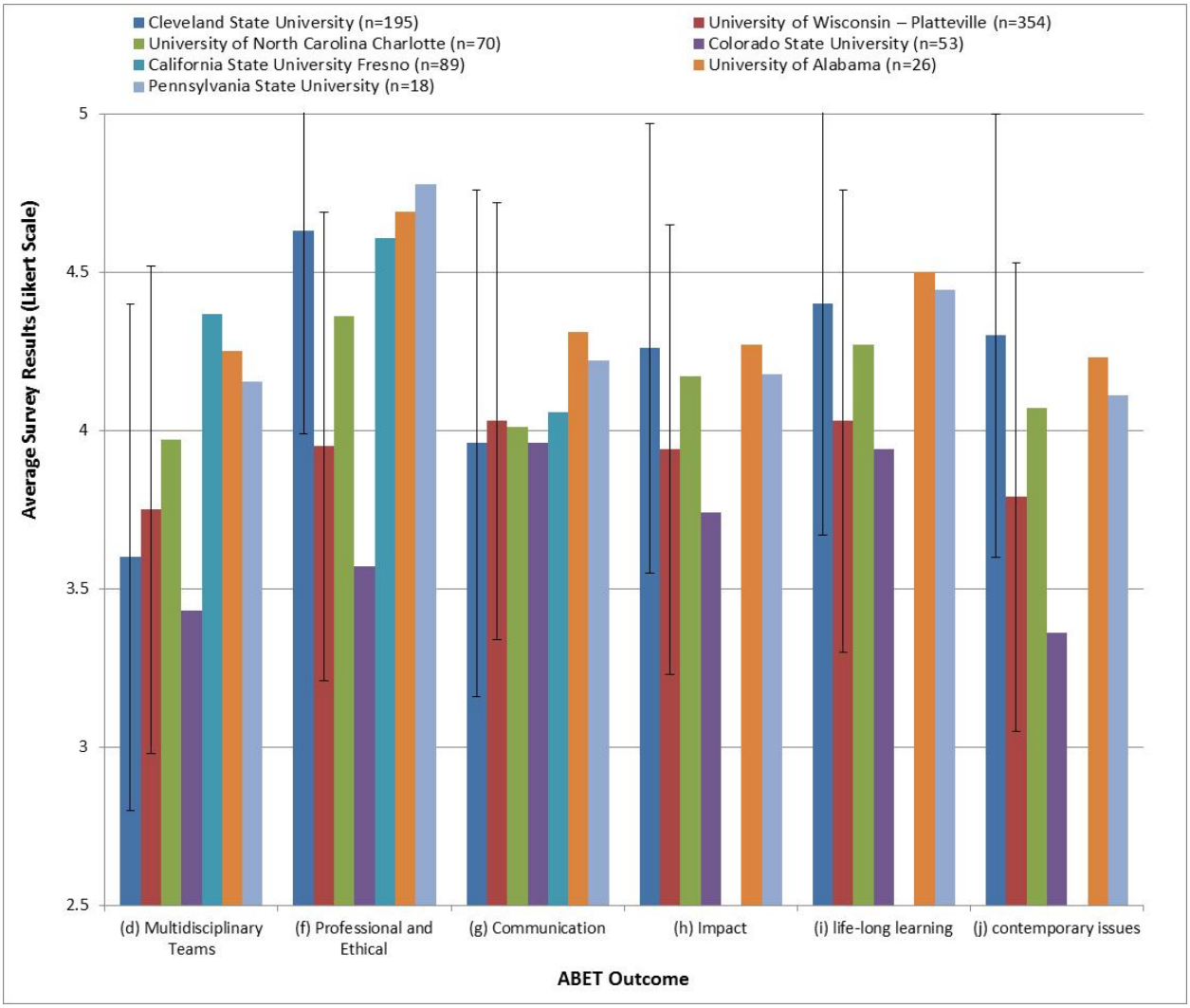

Figure 1 – Average results for all Universities for the professional ABET outcomes. Error bars represent one standard deviation for Cleveland State University and University of Wisconsin – Platteville.

- Student outcome (f) an understanding of professional and ethical responsibility – the results for this outcome were consistently high, averaging 4.63 at Cleveland State University and 3.95 at University of Wisconsin – Platteville, with other average values ranging from 4.36 to 4.78, with the exception of one low value of 3.57 at Colorado State University. Earlier work showed that students readily grasped the professional and ethical issues involved in failure cases, as demonstrated through both student surveys and student focus groups[8], so the generally high scores were not surprising.

- Student outcome (g) an ability to communicate effectively – since many failures involve breakdowns in communication, relatively high results were expected for this outcome. Cleveland State University and University of Wisconsin – Platteville had overall averages of 3.96 and 4.03, corresponding to "agree." Results from other universities were very similar.

- Student outcomes (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 may be grouped together. The results for these three outcomes were relatively consistent – 4.26, 4.40, and 4.30 at Cleveland State University, and 3.94, 4.03, and 3.79 at University of Wisconsin – Platteville. Results were in the same range at University of North Carolina Charlotte, University of Alabama, and Penn State, although somewhat lower at Colorado State University. These questions were not asked at California State University Fresno, since these outcomes were not addressed in that particular course.

The discrepancy between Cleveland State University and University of Wisconsin – Platteville on student outcome (f), professional and ethical responsibility, seems to be significant, since it is greater than the standard deviation for Cleveland State University. This is worthy of further exploration. It is possible that the instructors at Cleveland State University placed more emphasis on these aspects of the cases. Also, at Cleveland State University, the highest results were for the CVE 403 and CVE 422 courses, which are generally taught in the senior year. Thus, the students in these courses might already have a greater appreciation for professional and ethical issues. At University of Wisconsin – Platteville one of the instructors generally highlights communication, organizational issues, and personal psychology more than the traditional ethical aspects. As a result, students might not readily perceive the links to ethics. However, there could other reasons such as the lapse of time between using the case study in the course and the time the survey was given (generally at the end of the course).

Conclusions

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.

Including failure case studies in various courses, and using student surveys as an indirect, quantitative assessment measure, can help programs demonstrate that these ABET outcomes are being attained.

Acknowledgements

This work was sponsored by the grant: "Implementation and Assessment of Failure Case Studies in the Engineering Curriculum," National Science Foundation Project DUE-0919487, $ 500,000, August 1, 2009 – July 31, 2013. Opinions expressed are solely those of the authors and not of the National Science Foundation.

Appendix – Example Survey Instrument

Civil Engineering and Engineering Mechanics
Student Course Survey

Course: ESC 211 Instructor: Example Term: Spring 2008

Please rate the following with respect to your overall perception of the use of failure case studies in this class.

	The case studies contributed to:	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
A	my ability to apply knowledge of mathematics, science, and engineering;	**5**	**4**	**3**	**2**	**1**
B	my ability to design and conduct experiments, as well as to analyze and interpret data	**5**	**4**	**3**	**2**	**1**
C	my ability to design a system, component, or process to meet desired needs, using the principles of equilibrium;	**5**	**4**	**3**	**2**	**1**
D	my ability to function on multi-disciplinary teams	**5**	**4**	**3**	**2**	**1**
E	my ability to identify, formulate, and solve engineering problems;	**5**	**4**	**3**	**2**	**1**

F	my understanding of professional and ethical responsibility	**5**	**4**	**3**	**2**	**1**
G	my ability to communicate my problem solutions effectively;	**5**	**4**	**3**	**2**	**1**
H	the broad education necessary to understand the impact of engineering solutions in a global and social context	**5**	**4**	**3**	**2**	**1**
I	my recognition of the need for, and an ability to engage in life-long learning	**5**	**4**	**3**	**2**	**1**
J	my knowledge of contemporary issues	**5**	**4**	**3**	**2**	**1**
K	my ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	**5**	**4**	**3**	**2**	**1**

If you marked "disagree" or "strongly disagree" on any of the above, please identify as specifically as possible what you perceive as problems and ways of correcting the problems. Also, please provide any other comments related to the class and your preparedness to complete it successfully. (use reverse side if needed)

How well did each of these elements contribute to your INTEREST in the course material?

	Very High	High	Moderate	Low	Very Low
Textbook readings	**5**	**4**	**3**	**2**	**1**
Classroom lectures	**5**	**4**	**3**	**2**	**1**
Homework and problem sets	**5**	**4**	**3**	**2**	**1**
Projects	**5**	**4**	**3**	**2**	**1**
Exams	**5**	**4**	**3**	**2**	**1**
Case study readings and supplements to lectures	**5**	**4**	**3**	**2**	**1**

How well did each of these elements contribute to your UNDERSTANDING of the course material?

	Very High	High	Moderate	Low	Very Low
Textbook readings	**5**	**4**	**3**	**2**	**1**
Classroom lectures	**5**	**4**	**3**	**2**	**1**
Homework and problem sets	**5**	**4**	**3**	**2**	**1**
Projects	**5**	**4**	**3**	**2**	**1**
Exams	**5**	**4**	**3**	**2**	**1**
Case study readings and supplements to lectures	**5**	**4**	**3**	**2**	**1**

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