
AC 2012-3071: THE ROLE OF EXPOSURE TO FAILURE CASE STUDIES ON STUDENTS' TECHNICAL AND PROFESSIONAL GROWTH: A MIXED METHOD APPROACH

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The Role of Exposure to Failure Case studies on Students' Technical and Professional Growth: A Mixed Method Approach

Abstract

A number of studies have assessed the value of including failure case studies in the civil engineering curriculum. While the value of exposure to failure case studies to students is well documented, their relative benefits on different aspects of the student (professional, technical, ethics, etc.) are not well documented. The purpose of the study is to assess the impact of including case studies in civil engineering and engineering mechanics courses on students' technical and professional development. The results, overall, confirm the value of including failure case studies in engineering courses. Student survey results show that they can help in attainment of all 11 ABET criterion 3 outcomes. ABET is the accrediting agency for engineering and technology. Statistical analysis of the survey results divided the 11 outcomes into 11 groups, technical development and professional development. Case studies can make strong contributions to both components. The impact is definitely affected by the type of course, and there also seemed to be a difference in impact between lower and upper division courses. This suggests that failure cases have greater impact after students have achieved a higher level of maturity and a stronger technical background. Work on this project is continuing with additional courses at the participating universities, and with additional university partners. This additional data will allow the researchers to investigate whether these patterns continue to hold.

Introduction

A number of studies have assessed the value of including failure case studies in the civil engineering curriculum. It has been argued that failure case studies should be integrated into the engineering curriculum, early enough in order for young professionals to connect with the problems encountered by engineers and perhaps trigger interest, excitement, and relevance of the profession. In other words, exposing students to factors that result to failure and disaster can help them learn how to create designs while minimizing the probability of failure^{1, 2, 3}.

While the value of exposure to failure case studies to students is well documented, their relative benefits on different aspects of the student (professional, technical, ethics, etc.) are not well documented. The purpose of the study is to assess the impact of including case studies in civil engineering and engineering mechanics courses on students' technical and professional development. Existing and new failure case studies are being included in a number of undergraduate courses offered across a number of semesters in a number of participating universities.

Universities and Courses in the Study

This manuscript reviews results from four of the universities, Cleveland State University, the University of North Carolina at Charlotte, Colorado State University, and Pennsylvania State University. The courses were taught by a total of six different faculty members. The descriptions of the courses that the cases were used in are provided below.

Cleveland State University

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 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 Engineering degree. ESC 211, CVE 312, and CVE 422 form a sequence.

The University of North Carolina at Charlotte (UNCC)

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. Three laboratory hours per week. (Fall)

This course is required for the Civil Engineering Technology degree.

Colorado State University

CIVE 466 – Design and Behavior of Steel Structures. Loads acting on a structure; behavior and design of steel members, connections, and systems.

This course is required for the Civil Engineering bachelor's degree.

Pennsylvania State University (PSU)

CE 100S Topics and Contemporary Issues in Civil and Environmental Engineering: First-Year Seminar exploring a specific topic or contemporary issue in civil and environmental engineering.

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.

These courses are both electives, the former in the Civil Engineering bachelors program, and the latter in the Architectural Engineering program.

Student Surveys and Focus Groups

Each semester, participating students respond to a survey designed to assess the extent to which failure case studies in the curriculums contribute to students' knowledge, abilities, and interests in the course. Examples of results from individual courses have been previously published². At Cleveland State University, focus groups were also held in each course, and results from focus groups are reported at the end of this paper. It was not possible to hold focus groups at the other universities.

A mixed-method of data analysis using both quantitative and qualitative approach is used to determine the extent to which usage of case studies can impact different aspects of student growth. Factors analysis with VARMAX rotation with Crombach Alpha reliability is used to identify aspects of students' growth. "Given a multivariate time series, the VARMAX procedure estimates the model parameters and generates forecasts associated with vector autoregressive moving-average processes with exogenous regressors (VARMAX) models. Often, economic or financial variables are not only contemporaneously correlated to each other, they are also correlated to each other's past values. The VARMAX procedure can be used to model these types of time relationships. In many economic and financial applications, the variables of interest (dependent, response, or endogenous variables) are influenced by variables external to the system under consideration (independent, input, predictor, regressor, or exogenous variables). The VARMAX procedure enables you to model the dynamic relationship both between the dependent variables and also between the dependent and independent variables."⁴ Content analysis is also used to identify different themes from the focus group data.

The surveys had two parts. For the first part, students were surveyed as to whether the use of failure case studies in the course contributed to the attainment of ABET student outcomes⁵. The surveys asked "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:"

1. an ability to apply knowledge of mathematics, science, and engineering
2. an ability to design and conduct experiments, as well as to analyze and interpret data
3. 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
4. an ability to function on multidisciplinary teams
5. an ability to identify, formulate, and solve engineering problems
6. an understanding of professional and ethical responsibility
7. an ability to communicate effectively
8. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
9. a recognition of the need for, and an ability to engage in life-long learning
10. a knowledge of contemporary issues

11. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice⁵.

These, of course, correspond to ABET general criterion 3 outcomes a – k⁵. Students responded using a 5 point Likert scale, with 5 = Strongly Agree, 4 = Agree, 3 = Neutral, 2 = Disagree, and 1 = Strongly Disagree.

The second part of the survey addressed how different components contributed to interest in and understanding of the course material. Again, a 5 point Likert scale was used, with 5 = Very High, 4 = High, 3 = Moderate, 2 = Low, and 1 = Very Low.

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

1. Textbook readings
2. Classroom lectures
3. Homework and problem sets
4. Projects
5. Exams
6. Case study readings and supplements to lectures

How well did each of these elements contribute to your UNDERSTANDING of the course material? The six items were the same as above.

It should be mentioned that the inclusion of projects on this list presented a problem for data analysis, because not all of these courses necessarily included projects. In future analyses, the results if projects are excluded from the data set will be examined.

Research Methodology

Data Sources:

There were two sources of data for the study. The first is the student surveys designed to assess students' perception of the benefits of inclusion of failure case studies in the course. Each semester students in specific courses, where failure case studies were discussed, responded to a survey. The survey was designed to assess the extent to which failure case studies in the course contribute to students' skills and abilities, and interests, in the course as well as their understanding through course resources (lectures, homework, textbooks, projects, exams, and case studies). This source yielded quantitative data based on 279 student respondents.

The second source of data was a series of focus groups conducted in certain classes in one of the participating universities. Focus groups provided qualitative data based on four themes: (1) Knowledge and understanding of failure cases; (2) Usefulness of inclusion of failure case studies in the course; (3) Problems in the presentation of failure case studies in the course; and (4) Suggestions for a more effective inclusion of failure case studies in the course.

Data Analysis:

A mixed-method of data analysis using both quantitative and qualitative approach is used to determine the extent to which usage of case studies can impact different aspects of student growth. For the quantitative data, factors analysis with VARMAX rotation with Crombach Alpha reliability was used to identify dimensions of students' growth. The dimensions were then treated as the primary outcomes of the study. The univariate one way analysis of variance (ANOVA) was used to determine the significance of the differences in students' growth in these dimensions by course type (Structural Analysis, Freshman Seminar, Graduate Elective, and Planning and Estimating) and course level (early versus later).

Dimensions of Growth: Based on 279 students' responses from four universities, two factors (dimensions) of students' growth, namely technical and professional development have been identified with Alpha Reliability of 0.82 and 0.75 respectively. The reliability Alpha of 0.6 or higher is considered large and acceptable. It is not recommended to create a construct based on items whose reliability coefficient is less than 0.56⁶. There are also those aspects of the course that contributed to students' growth in interests. Two factors, one capturing the contribution of lectures, home-works, and exams, with a reliability coefficient of 0.71 and the other for textbooks, projects, and case studies with reliability Alpha 0.52 were identified. In addition, two factors related to aspects of the course that contributed to students understanding were identified. The first representing a combined contribution of home-work and exams with coefficient Alpha of 0.67 and the other representing projects and case studies with Alpha of 0.68 were identified. Detailed information about these six dimensions are presented in Table 1. The objective is then to analyze the extent to which integration of case studies in civil engineering and engineering mechanics courses can impact students' development in each of these six dimensions.

Table 1: Cronbach Alpha reliability for the six dimensions of students growth

Dimension	# of items	Alpha
Contributions to abilities & skills:		
Technical development	7	0.817
Professional development	4	0.751
Contributions to interests:		
Factor 1 (lecture, home-work, exams)	3	0.707
Factor 2 (textbooks, projects, case studies)	3	0.523
Contribution to understanding:		
Factor 1 (home-work and exams)	2	0.665
Factor 2 (projects and case studies)	2	0.676

The data analysis sorted the 11 ABET outcome items into two groups. It was found that items 1 through 5, 7, and 11 were grouped together into factor 1, and items 6 and 8 through 10 were

sorted together into factor 2. On reflection, the authors decided to term these factors “technical development” and “professional development.”

The outcomes grouped under technical development mostly refer to the “number crunching” skills in engineering, specifically outcomes 1 through 3, 5, and 11. The other two, items 4 and 7, can be thought of as soft skills that relate closely to technical skills. These are “an ability to function on multidisciplinary teams” and “an ability to communicate effectively.”

In contrast, the outcomes grouped under professional development, related to professional and ethical responsibility (outcome 6), the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context (outcome 8), a recognition of the need for, and an ability to engage in life-long learning (outcome 9), and a knowledge of contemporary issues (outcome 10).

The survey results for contributions to interest and contributions to understanding also sorted the data into two factors each, but the factors were different.

For the contributions to interest, factor 1 grouped lectures, homework, and exams together, and factor 2 grouped textbooks, projects, and case studies together.

For contributions to understanding, factor 1 grouped homework and exams together, and factor 2 grouped projects and case studies. The other two variables, lectures and textbooks, had a reliability coefficient of 0.19 and thus were found not to be internally consistent.

This grouping makes some sense. It is expected that homework and exams would be grouped together, since these are the components of the course that contribute to student grades. It also makes sense that case studies and course projects (when used) would be grouped together, since these are open-ended components that encourage exploration.

Quantitative Research Findings

Course Type:

The data were also analyzed for the effect of course type. For purposes of this analysis, ESC 211, CVE 312, CVE 422, and CIVE 466 were grouped as structural engineering courses. CE 100S, AE 537, and CVE 403 were analyzed separately as Freshman Seminar, Graduate Elective, and Planning & Estimating, respectively. The ETCE 3163L course was not included for this particular analysis. It should be further noted that all of the courses except CE 100S and AE 537 are required for their respective degree programs.

Results are shown in Table 2, and in Figures 1 through 6, respectively. The results in Table 2 show statistically significant differences at 0.01 Alpha level in all six dimensions by course type (Structural Analysis, Freshman Seminar, Graduate Elective, Planning & Estimating). Figures 1-6 illustrates these variations by course type.

Table 2: Analysis of variance results for the differences in students' development in the six dimensions by course type.

Dimension	F-value	P-value
Contributions to abilities & skills:		
Technical development	5.47	0.001
Professional development	6.94	0.000
Contributions to interests:		
Factor 1 (lecture, home-work, exams)	6.56	0.000
Factor 2 (textbooks, projects, case studies)	7.35	0.000
Contribution to understanding:		
Factor 1 (home-work and exams)	10.37	0.000
Factor 2 (projects and case studies)	6.62	0.000

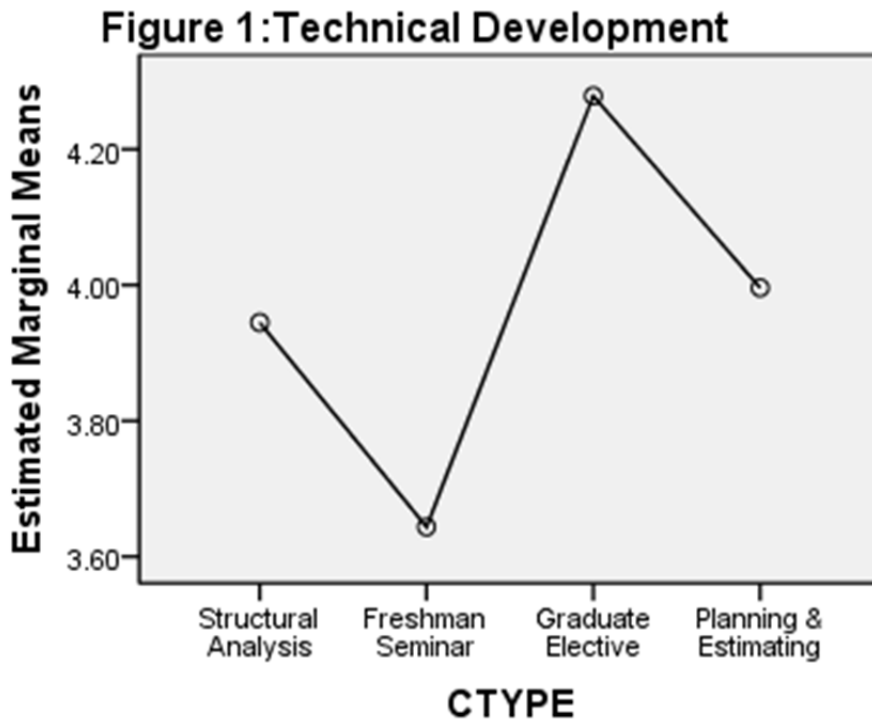


Figure 2: Professional Development

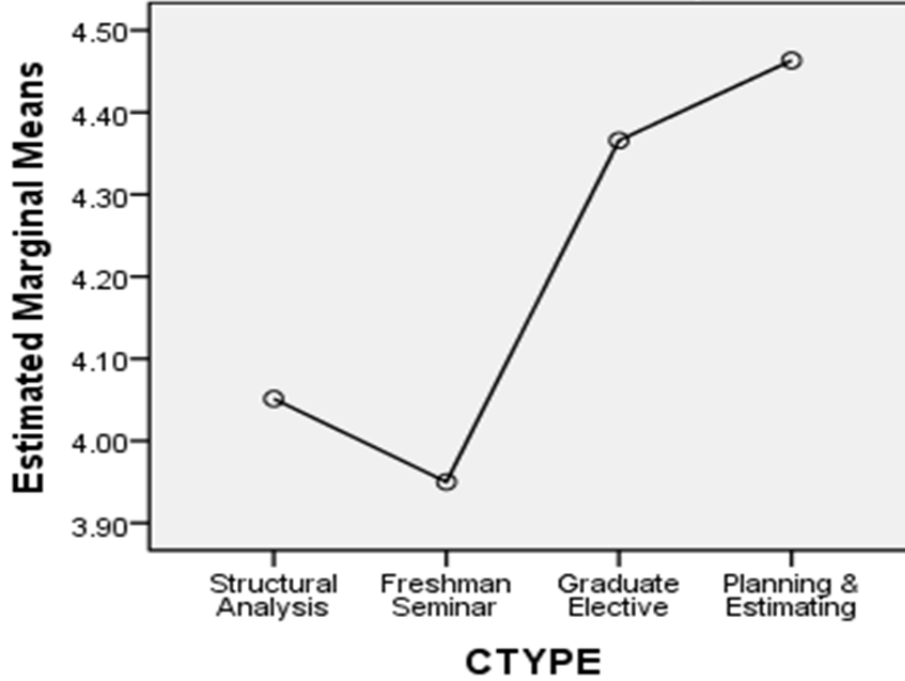


Figure 3: Interests through lectures, homework, & exams

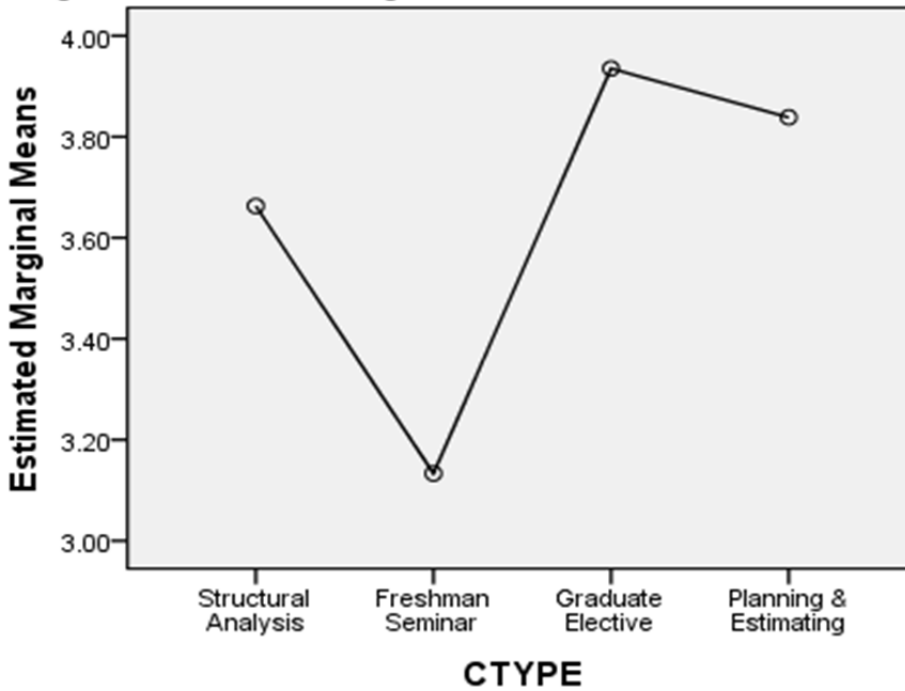


Figure 4: Interests through textbooks, projects, & case studies

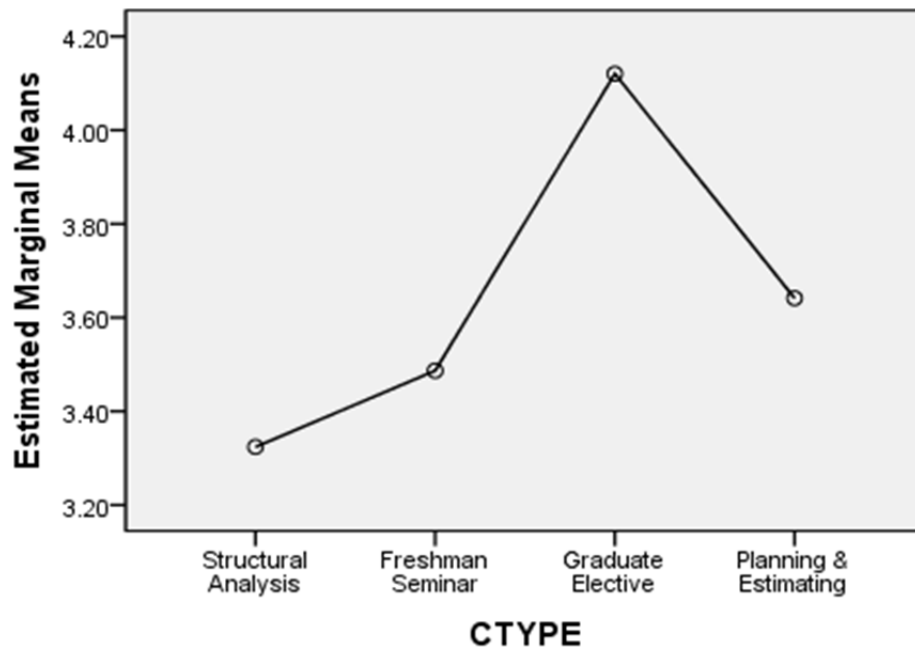


Figure 5: Understanding through homework & exams

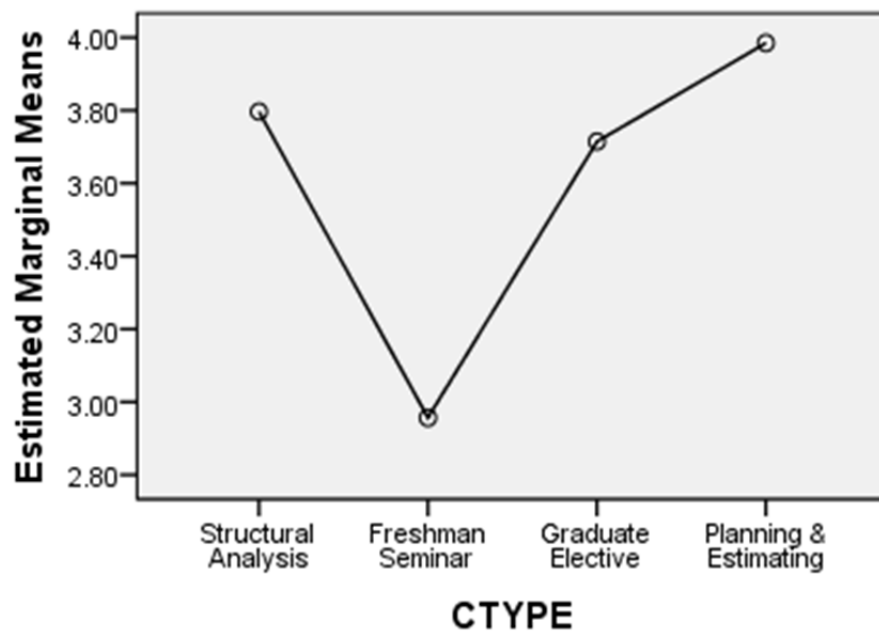


Figure 6: Understanding through projects & case studies

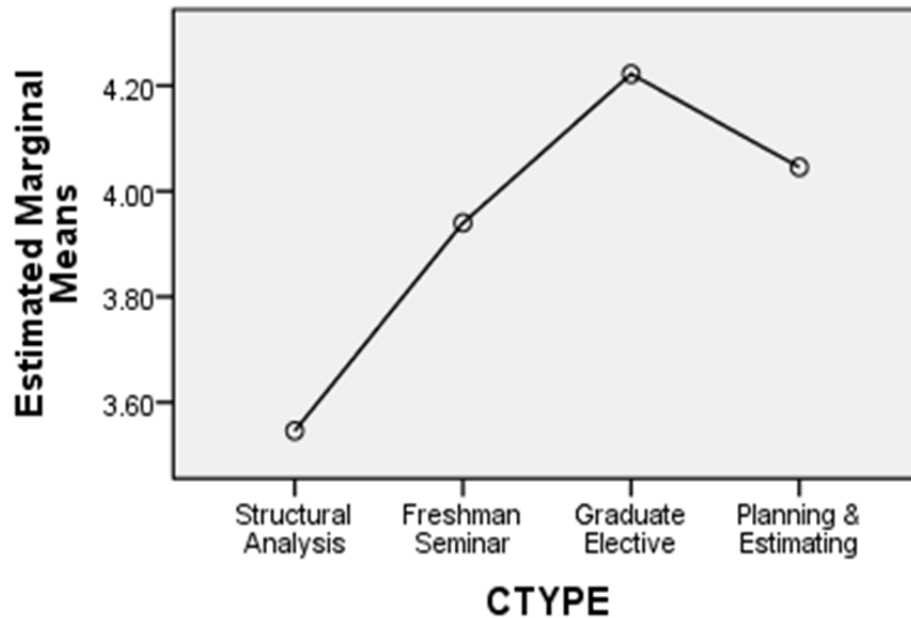


Figure 1 shows that the grouping of structural analysis courses and the planning and estimating course had strong impacts for technical development, and the graduate elective course had an even stronger impact. The impact of the freshman seminar course was less. This is not unexpected, since at this point the students have very little technical background to relate to the cases. The graph is based on the marginal means (average value of the outcome or dimension for each specific group).

Figure 2 shows that all courses had a strong impact on professional development, although the freshman seminar was again lower. The highest impacts were in the graduate elective and planning & estimating courses. This makes sense, because these courses allow more discussion of the professional and ethical aspects of failure cases. In contrast, the amount of technical information that has to be conveyed in the structural analysis courses allows little time for deep discussion of professional aspects.

Figures 3 and 4 show the impact on interest by course type. The impact of factor 1 (lectures, homework, and exams) are relatively low and roughly the same, except for the freshman seminar which once again is relatively low. The impact of factor 2 (textbooks, projects, and case studies) is a bit higher except for the grouping of structural analysis courses. The greatest impact is for the graduate elective course.

Figure 5 and 6 show the impact on understanding by course type. The impact of factor 1 (homework and exams) follows a similar pattern to that shown in figure 3 for interest. The impact of factor 2 (projects and case studies) is high, with the lower result for the grouping of structural analysis courses, which is a similar pattern to that shown in figure 4 for interest. Note that the factors for interest and understanding are not exactly the same.

The result generally shows that in most of the six dimensions, the highest impact was in the Graduate Elective and the lowest in the Freshman Seminar. High impact was also evident in the Planning & Estimating course for the professional development dimension as well as in the interests through lectures, homework, and exams; and understanding through projects and case studies.

Course Level:

To investigate whether the impact was greatest for lower or upper division courses, an additional grouping was created. Two lower division courses, CE 100S and ESC 211, were grouped together. Four courses normally taught at the senior or graduate level, CVE 422, CVE 403, CIVE 466, and AE 537, were also grouped together. The intermediate level courses ETCE 3163L and CVE 312 were left out of this analysis. Results are shown in table 3.

Table 3: Analysis of variance results for the differences in students’ development in the six dimensions by course level.

Dimension	F-value	P-value
Contributions to abilities & skills:		
Technical development	3.43	0.066
Professional development	0.05	0.824
Contributions to interests:		
Factor 1 (lecture, home-work, exams)	9.69	0.002
Factor 2 (textbooks, projects, case studies)	0.01	0.938
Contribution to understanding:		
Factor 1 (home-work and exams)	10.60	0.001
Factor 2 (projects and case studies)	0.18	0.675

The results in Table 3 show statistically significant differences at 0.01 Alpha level were observed in the dimensions of contributions to interests through lectures, homework, and exams ($F = 9.69$, $p = 0.002$); as well as contributions to understanding through homework and exams ($F = 10.60$, $p = 0.001$) by course type. In both of these cases, the impact was greater in the upper division than the lower division courses.

Results of the Focus Groups

For logistical reasons, focus groups were only carried out at Cleveland State University. Thus, the only courses with focus group results are ESC 211 and CVE 312, 403, and 422.

Knowledge and understanding:

Students had clear knowledge and understanding of specific recent as well as historical failure cases and found the discussion of these case studies to be interesting. Some singled out cases such as the Montreal Olympic Games case and the Quebec and Silver Bridge. To them, these failure cases raised the issues of liability; ethics; training of contractors; issue of effect – effects industry, construction law/management and design (using current methods). Other concerns were loss of life; lawsuits; loss of license; and feelings of guilt. In many of these focus groups, students noted with concern that the failures were mainly due to human error.

Usefulness:

Focus group student participants generally felt that reviewing the failure case study added a real-life dimension to what happens when things go wrong; and made them realize the importance of communication. The review of these case studies also showed real life implications – not just sitting in class theorizing what could happen. The students believed that the case studies would change the way they will approach things – to look for errors and be more careful because you're dealing with human life. They also observed that case studies would help them achieve a real world perspective, understand practical considerations for construction, and minimize chances of failure. They also felt that discussions helped them appreciate the need to be more careful and the need to make everyone more accountable.

Problems:

In most of the focus groups, no problems were mentioned in the presentation of case studies. However, some students voiced lack of usage of multimedia facilities to demonstrate the failures was a problem.

Suggestions:

A number of suggestions that students felt would improve the presentation of failure case studies in the courses were presented. They included:

- Increasing the number of failure case studies to cover more recent (such as Minneapolis bridge collapse) as well as the historic ones.
- Creating an elective class on just failure case studies and have it open to more than just engineering students such as history and sociology students.
- Would like to hear of case studies resulting from computer-designed failures.
- Integration of case studies throughout the course content rather than presenting them as separate topics.
- Some students expressed the need to have graphical illustration of failure cases as they occurred.

Conclusions and Future Work

The results, overall, confirm the value of including failure case studies in engineering courses. Student survey results show that they can help in attainment of all 11 ABET criterion 3 outcomes.

Statistical analysis of the survey results divided the 11 outcomes into two groups, technical development and professional development. Case studies can make strong contributions to both components.

The impact is definitely affected by the type of course. For some of the courses, the impacts on technical development, professional development, interest, and understanding were consistently higher than others. This was particularly true for a graduate elective in forensic engineering, and the planning & estimating course which has used failure cases in depth for many years.

There also seemed to be a difference in impact between lower and upper division courses. This suggests that failure cases have greater impact after students have achieved a higher level of maturity and a stronger technical background.

Work on this project is continuing with additional courses at the participating universities, and with additional university partners. This additional data will allow the researchers to investigate whether these patterns continue to hold.

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