An Approach to Improving Student Learning of Civil Engineering Concepts Using Case Studies

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Abstract—Engineering educators, professional organizations and practitioner have long recognized the benefits of integrating engineering case studies, especially failures into the civil engineering curriculum. One key benefit is that it provides a pedagogical tool that encourages students to address the complex challenges faced by engineers in the real world. The Civil Engineering Faculty at the United States Coast Guard Academy has successfully integrated case studies in several undergraduate courses to reinforce technical concepts. Case studies provided opportunities for discussion of engineering principles and concepts as well as fostering professional development in ethics and life-long learning. This paper discusses the implementation of case studies and the benefits to student learning especially in identifying problems and developing alternative solutions. Assessment data indicate that the use of case studies enhanced students’ learning of engineering principles and improved their understanding of the problem-solving process.

Keywords—Case Study, Assessment, Student Learning, Bloom’s Taxonomy

I. INTRODUCTION

A vast amount of published literature emphasizes that learning and retention are enhanced by engaging students in real project activities which simulate the actual work environment. Engineering educators have tried various learning paradigms such as: case studies, project-based learning, interactive learning, active learning, role playing, flipped classroom and computer simulations. These activities, complement the traditional classroom lecturing and are used by engineering educators to achieve a higher level of learning based on the six levels of cognitive domain in either the original Bloom’s Taxonomy [1] or the Revised Bloom’s Taxonomy [2]. The revised levels of learning (lowest to highest) include: (1) remembering (knowledge), (2) understanding (comprehension), (3) applying (application), (4) analyzing (analysis), (5) evaluating (synthesis), and (6) creating (evaluation). Educators have used Bloom’s Taxonomy of learning to measure the student’s level of understanding, evaluating, and creating engineering solutions.

Several engineering educators have tried to infuse case studies in the civil engineering curriculum or establish standalone case study courses. For example, Akili [3] described the steps taken in planning, developing, and executing a case study or case history course in geotechnical/foundation engineering at Iowa State University. This course focused on cases that demonstrated the geotechnical practices in the region, pedagogies of engaging students in a collaborative learning environment, and allowing students to develop effective communication skills. Students in this course were required to be an active participant in the group and open class discussions. Cases were normally used to extend the learning experience beyond the traditional classroom activities. The case studies used in this course were related to real world issues that exposed students to the analysis and decisions encountered by practicing engineers.

Delatte, et al. [4] reported the results of various pilot studies that were performed over several semesters to assess the use of failure case studies in the civil engineering curriculum at Cleveland State University (CSU). Student learning through failure case studies was assessed through homework questions, exam questions, surveys, and focus groups. Students commented during the focus groups that the cases helped them make the link between theory and practice. It also helped build engineering identity and it demonstrated the relevance of the technical information presented in engineering courses to the real world. This project extended the work of implementing and assessing case studies at CSU to thirteen other participating universities. A number of educational resources including a website were developed to provide easy access to engineering students, educators, and practicing engineers.

Dai, et al. [5] introduced a case study undergraduate course in the civil engineering program at the Tongji University, China, to enhance learning and make the shift from deductive teaching model to inductive instructional strategies. The course was designed to facilitate the use of laboratory testing equipment as part of the case study investigations. Typical failure cases were obtained from the recent Wenchuan earthquake in China in order to prepare students to assimilate the post-disaster field investigation of failure modes. Students were taught the basic principles of seismic design and the practical engineer’s responsibilities to the general public during the lectures. The case studies were used to involve students in seismic design, improve advance knowledge and
comprehension, and promote the professional and ethical responsibilities.

Similar attempts to enhance student learning and understanding of engineering principles are in progress at the United States Coast Guard Academy (USCGA) by integrating case studies into the curriculum. Solutions to real-world engineering problems are more complex and they require engineers to address various issues such as uncertainties, technical and nontechnical constraints, political, cultural, economic, communications, and the consideration of alternatives. One of the objectives of integrating case studies into the curriculum is to simulate these real-world scenarios. This paper is a work-in-progress and focuses on how case studies continue to be incorporated in several civil engineering courses at the USCGA. The emphasis of this paper is on three senior level courses that use case studies to tie together technical aspects, ethical issues, procedural issues, and to engage students at a higher level of thinking and learning.

II. CASE STUDIES IN CIVIL ENGINEERING CURRICULUM AT USCGA

The Civil Engineering Faculty at USCGA has successfully integrated case studies in several upper level undergraduate courses. These cases were used to reinforce technical concepts while providing an opportunity for discussion of engineering principles as well as fostering professional development in ethics and life-long learning. In this approach, case histories that tie together technical aspects, ethical and professional issues are identified and selected. These cases require students to synthesize or evaluate the technical and nontechnical issues as compared with the concepts and principles they have learned in their engineering and general education in humanities and science courses.

This paper focuses on the implementation of case studies in two required senior design courses, Geotechnical Engineering Design and Reinforced Concrete Design, and in an elective course, Water Resource Engineering. As part of the ABET requirement of depth and breadth in four civil engineering sub-disciplines, the Geotechnical Engineering Design course was introduced into the civil engineering curriculum at USCGA in 2009 as a graduation requirement. The course is purely project-based with open ended problems that require students to make decisions and develop alternatives, similar to what is expected in actual engineering practice. By balancing the need for fundamental engineering instruction with that of cooperative learning, the development of problem-solving skills required for engineering practice is promoted in this course. The case studies used do not only involve design, construction but also legislative disputes to simulate real-life engineering practice.

The Reinforced Concrete Design course has been a traditional required course where students learn about the basic analysis and design of beams and columns, floor slab design, serviceability, and shallow foundation design. The course incorporates unique requirements of various team projects that include: EXCEL programming projects; and the analysis, design, construction, and testing of full-scale reinforced concrete beams. Recently, the course was modified to include case studies and a multi-step design project that require students to analyze and design key components of a multi-story building. The new building design project was developed and coordinated with two other courses in order to simulate real-world projects. The addition of case studies and multistory building project was essential to transition the course to project-based learning and to advance student comprehension of reinforced concrete design. Several case studies have been identified from the published literature and strategically introduced throughout the semester. Case studies are used to either introduce a new topic in the course or highlight critical design and construction practices that should be considered during the design process. The case studies enhanced the classroom environment by engaging students in the discussion of what went wrong and what to do in avoiding similar mistakes when designing key components in a structure.

The Water Resources Engineering course was first offered in the Spring of 2014 as an elective course in the civil engineering curriculum. This course offers a basic introduction to the field of Water Resources Engineering. The goal is to expose civil engineers to a broad range of topics relevant to the field of water resources. Course topics include surface and groundwater hydrology, rainfall-runoff analysis, reservoir and river routing, probability and frequency analysis, computer modeling, water excess management/control, and watershed management. Case studies are used in this course to expose students to issues surrounding water resources and to challenge them to realize that engineering decisions are not solely based on hand calculations or computer simulation.

In general, case studies were used in these three upper level courses to enhance the learning experience beyond the traditional classroom activities and expose students to the analysis and decisions encountered by practicing engineers. The case studies provided background for specific topic (module), served as materials for problem formulation and identification, and served as illustrations for examples of engineering concepts and principles covered in these courses.

The case studies tie together technical aspects, ethical issues, procedural issues, and help students engage in a higher level of thinking to synthesize and evaluate relevant concepts. The case studies were used strategically throughout the semester to provide students with an opportunity to make the connection between theory and real-life applications, as well as to generate interest in open discussion of engineering problems.

Suitable case studies were extracted from the following widely published resources: archives of the Association of Engineering Firms Practicing in the Geosciences [6], Delatte [7], Kaminetzky [8], Watkins [9], Johnson et al. [10], Gleick [11], and Rouge River project [12]. Examples of the case studies students received a week ahead of time in the three courses are summarized in Table 1.
students are encouraged to question the validity of each proposed solution.

5. Selection of a course of action – Having completed the first four steps, students are then encouraged to identify suitable approaches or solutions they think is most appropriate to address the issues based on the available information. Basically students are asked to select or identify the most appropriate course of action to resolve the problem. The cases presented may not have a straightforward solution.

6. Recommendation of an implementation plan – If a solution can be identified, students are required to propose some form of implementation plan that may need to address any constraint defined in the problem statement.

III. ASSESSMENT

The template described above was used in the three courses as a standard grading rubric. Sample performances on case study 1 and 4 (see Table 1) used in the Geotechnical Engineering course are shown in Figures 1 and 2. In the figures, “Exceeds,” “Meets” and “Below” represent scores of at least 90%, 70%-89%, and less than 70%, respectively. General guidelines were given at the beginning of the semester with more discussions and emphasis followed based on student performance after submitting their analysis of each case. For example, Figure 1 indicates that most of the students adhered to the template guidelines and showed good understanding of the concepts. Performance was fairly good on most components of the rubric. However, 55% and 67% of students performed poorly on “problem statement” and “alternative solutions”, respectively on the first case study presented in the Geotechnical Engineering Design course. Therefore, more emphasis and guidance were provided on the subsequent case studies and this resulted in modest improvement in student performance on case study 4 as shown in Figure 2.

Fig. 1. Student performance geotechnical engineering case study 1

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Problem Description/Statement</th>
<th>Learning Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1: University building expansion, NJ</td>
<td>Dewatering and excavation support. Several challenges including underground utilities and limited access.</td>
<td>Addressing construction management issue and selection of suitable equipment.</td>
</tr>
<tr>
<td>Case 3: Looming tower of Pisa, Italy</td>
<td>Inadequate soil investigation, effects of differential settlement, selection of suitable soil improvement &amp; stabilization techniques.</td>
<td>Understanding of soil-structure interaction, importance of thorough site investigation and selection of suitable foundation system.</td>
</tr>
<tr>
<td>Case 4: Schuylkill Creek Bridge failure, NY</td>
<td>Scout, inadequate bridge inspection and maintenance.</td>
<td>Importance of investigation and proper maintenance of bridges. Importance of understanding hydraulic forces on foundations.</td>
</tr>
</tbody>
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TABLE I. EXAMPLES OF CASE STUDIES

<table>
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</tr>
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<tbody>
<tr>
<td>Cocoa Beach five-story cast-in-place concrete building collapse, FL</td>
<td>Inadequate design, poor construction, and quality control.</td>
<td>Addressing key construction issues including severe cracking and excessive deflection, proper rebar placements, punching shear strength, and lack of formwork design.</td>
</tr>
<tr>
<td>Skyline Center at Bailey’s Crossroad high rise concrete building, VA</td>
<td>Catastrophic collapse of a high rise building due to quality control and lack of formwork plan.</td>
<td>Importance of proper quality control related to punching shear, formwork (shoring and re-shoring slabs), and ensure proper concrete strength before formwork removal.</td>
</tr>
<tr>
<td>Flood control reservoir operation during the Great Midwest Flood of 1993</td>
<td>Following the Great Midwest Flood of 1993, concern was voiced that the US Army Corps of Engineers did not operate flood control reservoirs in an optimal manner therefore contributed to the damage.</td>
<td>Understand reservoir operating plans particularly for flood control; evaluate (in hindsight) the effectiveness of reservoir operations during an extreme flood event.</td>
</tr>
<tr>
<td>Combined Sewer Outflow (CSO) Case study</td>
<td>In the Rouge River Watershed, MI, water quality was improved through CSO reduction.</td>
<td>Practical understanding of how CSOs are reduced and further explanation of the detrimental effects of CSOs.</td>
</tr>
<tr>
<td>Three Gorges Dam, China</td>
<td>Case study provides an overview of challenges and decisions that were faced during construction.</td>
<td>Understand the complexity of the decisions that had to be made during the construction of this dam.</td>
</tr>
<tr>
<td>Watershed Management on Groundwater and Irrigation Potential in India</td>
<td>An increase in population has led to increased water demand for irrigation and agricultural purposes in semi-arid and rural areas of India.</td>
<td>Understand the impact of watershed management on the ground water and irrigation potential of a watershed facing drought like conditions.</td>
</tr>
</tbody>
</table>

Students were required to review each case and address key aspects on a template before class discussions. The grading rubric template provided students with guidelines of the following key aspects that must be considered while reviewing each case study:

1. **Review the case content** – Students were required to provide a 2-4 sentence summary on the case or “bird’s eye view” of the case. Key questions that must be addressed include: What is going on in the case? What are the facts of this case?

2. **Identification of the problem** – Students were required to identify the key issues of the case and develop a problem statement.

3. **Collection of relevant information** – In general, no additional literature review or search for new information is formally required. However, students are expected to make the connection with already acquired knowledge and evaluate if any additional information is required to fully assess the case. In a few of these cases, instructors purposefully withheld key information to get students more engaged in this step.

4. **Development of alternatives** – Students were encouraged to come up with alternative ways of solving the problem. Open classroom discussions facilitate the exchange of ideas and students were encouraged to question the validity of each proposed solution.
In general, students struggled to adequately identify and develop problem statement and 50% of the students still performed below expectation in case study 4. The faculty is investigating suitable approaches to expose students to more opportunities of developing problem statement to enhance their understanding in this area.

Similar trends in student performance shown in Figures 1 and 2 were also observed in the Reinforced Concrete Design and Water Resource Engineering courses. Overall student performances in the three courses for the graduating class of 2015 are presented in Figure 3. The figure represents average overall student grades on four case studies in each course. Most students are either meeting or exceed expectations. The Geotechnical Engineering Design and Reinforced Concrete Design courses are both offered in the fall semester. Both courses are design-focused with a common semester project that further exposes students to high levels of critical thinking. The Water Resource Engineering course is offered in the spring semester as an elective. The grading rubric is under continuous review based on the feedback received from students and faculty experience during each semester.

In addition to the graded assignments, student feedback was collected using in-class surveys. The focus of the survey was to have students self-assess their understanding of the principles and provide feedback on the effectiveness of the instructional method in meeting the course objectives. Students commented that project-based learning and the use of case studies improved their learning and comprehension. It also enhanced their ability to make the connection between theory and practical applications. They felt better prepared to complete their capstone design project and ready to work as civil engineers.

IV. CONCLUSIONS

The Civil Engineering Faculty at USCGA has successfully integrated case studies in several undergraduate courses. This paper focused on the implementation of case studies in two required senior level courses, Geotechnical Engineering Design and Reinforced Concrete Design, and in an elective course, Water Resources Engineering. The selected cases were used to reinforce technical concepts while providing an opportunity for discussion of engineering principles as well as fostering professional development in ethics and life-long learning. Using case studies or project-based learning as an active learning methodologies are powerful tools educators can use to engage students in the learning process and help students make the connection between theory and practice. In general, students exposed to case studies and project-based activities achieve a higher level of learning through this exposure to real-world problems. It was also observed at the United States Coast Guard Academy that Students who experienced this process during the fall semester performed better on their capstone projects in the spring semester. It is anticipated that in the future, case studies will also be introduced in some lower level courses. This will enable faculty to monitor any progressive changes in students’ learning and professional skills resulting from the use of case studies throughout the Civil Engineering curriculum. With more targeted assessment data, faculty will be able to make continuous improvements to the program. The goal is to progressively infuse case studies and design throughout the four year Civil Engineering curriculum.

REFERENCES


