Using Case Studies to Characterize the Broader Meaning of Engineering Design for Today's Student

Pamalee A. Brady & John W. Lawson

ABSTRACT

Numerous organizations have undertaken the task of envisioning the education required to meet the engineering demands of the future. The ABET study EC2000, ASCE's Civil Engineering Body of Knowledge and Body of Knowledge 2 and the National Academy of Engineering have documented the need to change engineering education from its historical focus on technical content knowledge to include greater emphasis on professional issues and to integrate engineering practice into education. To this end teaching methods such as project-based learning, and the use of case studies are being explored to address these broader learning outcomes. Case studies in particular facilitate telling the stories of professional practice. This paper discusses the use of engineering case studies in design coursework with specific application to third year architectural engineering student learning. Introduction, application and discussion of several case studies are presented in the context of teaching building structural design. Along with the technical execution of system and member selection, computer analyzes and structural detailing that occur in these courses, broader concepts relating to professional roles and responsibilities, design team interplay, the design process, the construction process and professional practice ethics are investigated. The advantages of this altered approach to teaching engineering design are discussed.

INTRODUCTION

Numerous organizations have undertaken the task of envisioning the education required to meet the engineering demands of the future. The National Research Council begins with their assessment of what is currently missing from undergraduate education. In their report [11] they cite three "serious concerns" with present engineering graduates: 1) little knowledge of the design process, 2) inadequate knowledge of the role of technology in their professions and 3) little knowledge of business, economics and management.

ABET EC2000 [2] identifies specific outcomes that engineering graduates should achieve, often stated as "3(a-k)". These encompass outcomes focused on the technical aspects of engineering but further identify attributes related to professional practice including communication, teamwork, ethics, life-long learning and

engineering's relationship to societal and global issues. ASCE's Civil Engineering Body of Knowledge and Body of Knowledge (BOK) 2 [3, 4] emphasize these professional practice attributes by prescribing four outcomes encompassing more technical depth in a civil engineering specialty and additional breadth relative to project management, public policy and leadership. In the same vein the National Academy of Engineering in their report "Educating the Engineer of 2020: visions of engineering in the new century," [10] notes that the explosion of knowledge, the global marketplace for engineering services and the steady integration of technology in public infrastructures creates a growing need for interdisciplinary and system-based approaches and more involvement by engineers in the setting of public policy and participation in the civil arena.

PROFESSIONAL PRACTICE ISSUES IN FOCUS

With increasing complexity occurring in the profession, it is critical that engineers understand the broader context of the practice and where it sits within the framework of society. It is this "Big Picture" that is necessary to grasp and understand if engineers are to weigh competing priorities, make difficult decisions, develop practical designs, and accept responsibility. In the past engineering offices fostered the development of these broader professional issues within the initial years of employment. In today's fast-paced society with complex jobs and competing priorities for limited time, there has been less fostering within the profession of these skills and more relying upon skills acquired during formal classroom education. This broader perspective of professional issues has been a weakness in engineering curriculum. The expectation has become that engineering graduates must be well prepared to meet the new challenges of not only heightened technical complexity but also the escalating professional complexity.

The scope of professional practice skills that an engineer of the future must acquire becomes quite extensive. In undergraduate education there must be a balance struck with the scientific base, the technical core, professional and general education. How do we achieve these goals with an educational system that is already full to the brim with technical content? How should an engineering curriculum be organized to achieve these attributes and what are the best teaching and learning methods to accomplish competent engineering graduates? Each educational institution must evaluate what and how this knowledge and skill will be incorporated into the curriculum. While some references contend that adjustments to programs will not address the educational needs of future engineers and thus a wholesale change of the engineering curriculum is required, there are surely opportunities to make existing curricula better. Within the Architectural Engineering Department (ARCE) at California Polytechnic State University we have chosen to modify the existing curriculum with a mix of new courses and altered learning outcomes in existing courses to develop professional practice skills in our students. At the heart of our curriculum are design laboratories in structural systems, steel, wood and masonry and concrete building design. These laboratories follow lecture courses, focused on design of elements, and have the complementary objective of integrating element design, in accordance with the latest material standards, into complete structural

systems. Design projects form the basis of learning in each of the laboratories. Students are required to produce calculation sets and representative construction documents of their building design. These courses offer extensive practice in the design process and more recently we have begun to formally embed professional practice issues beyond engineering design in them. Further, a new capstone interdisciplinary experience concludes the undergraduate education program. Here students in architecture, construction management and architectural engineering undertake collaborative work to solve a multi-faceted design project. Design experience incorporating architectural vision, space planning, constructability as well as integrating building systems while balancing real world physical, owner, regulatory, code and contemporary constraints are the learning objectives of this course in addition to functioning effectively on an interdisciplinary team [12].

From the spectrum of professional skills needed by the engineering undergraduate the focus of our curriculum is directed to understanding collaboration and professional roles, providing clear and concise communication in both written and oral form, developing a deep understanding of professional responsibility and ethics, and embarking on lifelong learning within the context of design process. The authors believe that while the 'Big Picture' perspective does not neatly fit into a traditional engineering curriculum it can be successfully incorporated into existing coursework with the use of well-developed case studies rather than by means of new stand-alone classes for these subjects. It has been well established that the engineering education of the future needs to incorporate these professional issues in the classroom to face these challenges [3, 4].

CASE STUDIES FOR TEACHING THE BROADER VIEW OF ENGINEERING DESIGN

Case studies are a natural medium for teaching professional issues as they allow for problem solving in a context which typically pushes the traditional boundaries of engineering design. Using a case study the instructor can introduce a complex problem and allow the students to construct their own need for facts and guiding principles, ultimately to discover the broader theories necessary to resolve the problem. This approach supports the thesis that students learn when they can internalize a subject and process it through the prism of their own experiences; research has shown the effectiveness of "contextual learning" [15]. This method is also inductive rather than deductive as is typical in engineering education. In this approach, students are first given the reason why they need to learn this material and then challenged to make logical sense of a complex problem. This skill is imperative to successful life-long learning. The inductive approach to teaching and learning is supported by the best research on learning currently available and promotes desirable attitudes towards learning [14].

Case studies are originally from real-life stories. There is a setting, an array of characters, typically a plot with a struggle, and an outcome. Stories about professional practice provide valuable context for students to visualize their own professional future. Storytelling of a case study is an ideal conduit for students to experience real situations involving everyday people. Students are briefly immersed into the

unfolding events and imagine what they would feel, how they would think, and how they would act if confronted with similar circumstances . In a society that has embraced reality-based entertainment, it should come as no surprise that students are more engaged with real-life situations and struggles.

When presented in a story form structure the impact of the inductive case study to the student can be a very powerful learning device. This ability to weave factual information into a story with characters, feelings, attitudes, and struggles provides more than just better understanding and memorization [1]; it also creates an ideal vehicle for developing a sense of ethical behavior in students. Presenting a simple list of ASCE's Code of Ethics for memorization will unlikely achieve desired results. But engaging students with an emotional connection in a case study involving engineering judgment and ethical issues can actually begin to mold beliefs and attitudes through experiential feelings. This is very difficult to achieve in the classroom through any other method of instruction. In case studies, instructors can harness this high level of engagement to facilitate the transfer of knowledge, the encouragement of critical thinking, and the introduction of broader professional practice and ethics issues.

Case studies may be presented through elaborate or simple stories based on factual information of a real-life problem and how it was solved. But what are the sources of these facts? Frequently, available case studies seem to only involve spectacular failures or extraordinary ethical dilemmas. It is not surprising that case studies involving the Hyatt Regency skywalks, the Citicorp tower, and the Space Shuttle Challenger are most popular. These "high-profile" case studies are normally well documented with numerous perspectives and commentary available for review. One drawback of always using case studies of extraordinary events is their detachment from the more common aspects of day-to-day events in the engineering profession. While it is important to learn from these unique events, engineering students also need to be exposed to issues in a more typical context of the profession. Educators with practitioner experience have valuable stories to share with students providing perspective and a contextual setting for coursework; however, educators that have been limited to academia will need to search elsewhere.

There are books, journals and professional organization collections of case studies that have been established for the purpose of educating students and professionals in engineering, architecture and construction. Books that provide useful case studies include Beyond Failure: Forensic Case Studies for Civil Engineers [6], Structural & Foundation Failures: A casebook for architects, engineers, and lawyers [9] , Construction Failure [7] and Failure Mechanisms in Building Construction [13] Several professional organizations along with ASCE have developed resources valuable for teaching with case studies. These include the ASCE Journal of Performance of Constructed Facilities as well as the proceedings of the ASCE Forensic Engineering Congress conducted every three years. A number of organizations sponsor websites that are repositories for case studies. These include The National Academy of Engineering's Center for Ethics, Engineering and Society (CEES) which maintains a large clearinghouse of case studies for engineering and research; The American Society for Engineering Education (ASEE) sponsors a library of case studies at The Center for Case Studies in Engineering at the Rose-Hulman

Institute of Technology and The National Science Foundation which sponsors Failure Case Studies (http://matdl.org/failurecases). The authors have used both high profile failure case studies from such sources as well as their own experience to teach professional issues in the classroom.

A SPECTRUM OF CASE STUDY LESSONS

The dramatic story of the Hyatt Regency Walkway Collapse is a case that serves to highlight many professional issues as well as emphasizing the continuity required in the design and construction process. This case has been used by both authors in several courses for upper-class students. Learning objectives vary depending on the use of the case in a particular course. While employing different approaches both authors have used the case in design laboratories to highlight broader learning objectives of professional practice. The learning objectives include: 1) exhibit an understanding of professional ethics, 2) identify the importance of cross disciplinary communication, 3) understand roles and responsibilities in design/construction, 4) characterize project delivery systems, 5) identify importance of detailing and 6) value teamwork and cooperation – different perspectives, strengths.

One author uses a two-week period to interject the case study into the scope of the broad quarter-long design problem. Topic threads on project delivery systems, licensure, ethics, communication and the roles of individuals in a design team are woven into lessons on design of a steel building from schematic design through detailing and development of construction documents. Through the reading of selected papers and discussion via an electronic blackboard student teams answer questions on the technical / human / organizational / socio-cultural aspects of case. The students summarize their work in a presentation expressing the lessons learned from the case information.

Using a different approach one author's case study lesson involves only several days. The instructor begins the presentation by simply introducing an apparently hypothetical design challenge faced by an architect and engineer involving an elevated walkway across an atrium space. Students break into small groups and develop schematic design solutions to two stacked, visually floating, walkways across an atrium space. At the exercise conclusion, the instructor can compare and contrast the different approaches discovered by the groups. While some differences may simply be a matter of different perspectives, other differences could be attributed to intentional ambiguous communications from the instructor. An important lesson in clear communications and the pitfalls of inappropriate assumptions can be taught here. The instructor then explains that this exercise is actually based on a real design problem, and then discloses the *as-designed* solution. Once it is revealed that this is a real project, the power of storytelling can take hold by introducing more imagery of the actual setting, backgrounds of the key participants, challenges faced by the design team. Like any captivating story, there must be an emotional surprise; and the revelation of the disastrous collapse serves this purpose. With the disaster now revealed the students search for answers. As the instructor discloses more information from the investigation of the collapse, students are periodically polled with a show of hands or electronic clickers to observe opinion shift. The revelations of revised

connections, communication disconnects, and shop drawing approvals dramatically shift student opinion on the case while teaching important professional issues. By immersing students into a difficult situation of a case study and forcing them to decide on the correct course of action, this experiential approach can instill professional ethics very successfully. If this approach has engaged the students both intellectually and emotionally, the case study has provided valuable context to introduce ASCE's and NSPE's Code of Ethics to reflect on and other professional issues sought by industry. Either approach can be incorporated into either a lecture or design lab course.

Individual case studies may also be used to highlight a single principle in the design or construction process. The authors have drawn on several cases from both professional and lay literature to motivate lessons on loads and detailing. Bast and Maschke's paper [5] examines an unusual failure of a bolted connection in a steel frame building which supports a lesson on the effects of live load and the differential movement of structural members. The importance of design loads, effects of design changes in construction and most importantly communication and decision making may be emphasized in the telling of this story.

Case study lessons may also be developed from a composite of a number of instances of an event or from a history of events. The histories of earthquake damage and its impact on code development provide a sequence of events which can be formed into a teachable case study. Again in the steel design laboratory one such composite case study has been used to emphasize the need for life-long learning; the study is based on damage to steel moment frame buildings in the Northridge earthquake. This case study examines the history of relevant research on steel moment frame systems, how the research was incorporated into the state of the practice prior to the Northridge earthquake, the earthquake damage due to steel moment frame buildings and the research following the earthquake leading to changes in the design codes, Additional learning objectives that come from this case study include the value of research, the importance of detailing and the critical relationship between construction and design, calculation and performance.

Case studies drawn upon personal experiences are no less important than the high-profile ones that are well-documented in other sources. Students have a thirst for the many unpublished lessons learned in a design office in addition to the dramatic lessons of a publicized national disaster. One author who consults periodically as a construction litigation expert witness finds numerous stories to capture the attention of the students. One lawsuit involved a roof collapse of a warehouse building storing expensive consumer electronics. With the blockage of the roof drainage system during a rainstorm, the author was able to develop a case study encompassing numerous interdisciplinary professional issues: Was the roof structure of sufficient strength to support a 100-year rain? Did the architect provide sufficient drainage capacity? Was the city's planning department partially responsible for requiring roof parapets with no overflow scuppers? Did the landscape architect play a role in the collapse by planting tall deciduous trees adjacent to the building causing leaves to block the drains? These were all direct questions asked during the litigation and argued by all sides. In the classroom, students become exposed to probability

and risk, factors of safety, the design process, contractual obligations among the parties, and a respect for unforeseen circumstances.

CONCLUSION

A good case study provides a much bigger picture of technical and humanistic issues that may be intertwined in a problem possibly with competing priorities. To make the learning inductive, the story is allowed to unfold slowly with key decisions withheld allowing for the students to conduct their own analysis and decision making. When presented in a story form structure, the impact of the inductive case study to the student can be a very powerful learning device. The process for constructing an effective student learning experience involves first identifying how the case may be used. What learning objectives, particularly those that support the broader issues related to engineering design practice, does the case facilitate? The goal of the case is to be a reflection of reality rather than to present good or bad engineering. Kardos and Smith [8] offer some helpful suggestions for writing engineering case studies but the principles that form a good story can guide the development of a compelling lesson. A good case study is taken from real life, consists of one or more parts, each part ending with problems and or points for discussion and includes sufficient data for the reader to address problems and issues. To place the case in the powerful form of a story the case study must employ a setting, characters, a sequence of events, conflicts and dilemmas. The importance of incorporating professional practice learning in the classroom has become essential in our fast-paced society. With the increasing demands on limited classroom time, case studies can be tailored to integrate professional practice issues into existing curricula; however, real world experience will still be required to fully develop the engineer required to solve the problems of our increasingly complex world.

REFERENCES

[1] Abrahamson, C. E., 1998. "Storytelling as a Pedagogical Tool in Higher Education," Education, Vol. 118.

[2] Accreditation Board for Engineering and Technology,. 1995. Engineering Criteria 2000, ABET, Inc., 111 Market Place, Suite 1050, Baltimore, MD 21202, http://www.abet.org/.

[3] ASCE Body of Knowledge Committee. 2004. Civil Engineering Body of Knowledge for 3the 21st Century: Preparing the Civil Engineer for the Future, Reston, VA, http://www.asce.org/raisethebar.

[4] ASCE Body of Knowledge Committee. 2008. Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future, 2nd Edition, Reston, VA, http://www.asce.org/raisethebar.

[5] Bast, W. and Maschke, M., 2006. "Bolt Failure at Gable Roof of 42-Story Building," Forensic Engineering Proceedings of the Fourth Congress, Cleveland, OH.

[6] Delatte, N., 2009. Beyond Failure: Forensic Case Studies for Civil Engineers, ASCE Press.

[7] Feld, J. and Carper. K., 1997. Construction Failure, 2nd Edition, John Wiley & Sons, NY, NY.

[8] Kardos, G., and Smith, C.O., 1979. "On Writing Engineering Cases," Proceedings of ASEE National Conference on Engineering Case Studies.

[9] LePatner, B. and Johnson, S. 1982. Structural & Foundation Failures: A casebook for architects, engineers, and lawyers, McGraw-Hill.

[10] National Academy of Engineering, 2005. Educating the Engineer of 2020 – Adapting engineering education to the new century.

[11] National Research Council Panel on Undergraduate Education, Committee on the Education and Utilization of the Engineer, Commission on Engineering. 1986. Engineering Education and Practice in the United States: Engineering Undergraduate Education, National Academy Press, Washington, DC.

[12] Nelson, J., Nuttal, B., and Estes, A., 2010. "Interdisciplinary Design: the Good, the Bad, and the Ugly," Proceedings of the ASEE Annual conference, Louisville, KY.

[13] Nicastro, D., 1997. Failure Mechanisms in Building Construction, ASCE Press, Reston, VA.

[14] Prince, M. J., and Felder, R. M., 2006. "Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases," Journal of Engineering Education, Vol. 95.

[15] Shuman, L., Besterfield-Sacre, M., McGourty, J., 2005. "The ABET 'Professional Skills' – Can they be taught? Can they be assessed?," Journal of Engineering Education ,Vol. 94, No. 1.