The International Journal of Engineering Education

Contents

Special Issue
Selected Papers from the 2014 Capstone Design Conference
Guest Editors
Steven Beyerlein—University of Idaho, USA
Jay Goldberg—Marquette University, USA
Susannah Howe—Smith College, USA
Scott Palo—University of Colorado, USA
Renee Rogge—Rose-Hulman Institute of Technology, USA
R. Keith Stanfill—University of Florida, USA

The capstone final year engineering project (FYEP) is the culminating learning experience of engineering programs. It requires students to demonstrate that they can integrate knowledge, skills and professional graduate attributes developed during the program and perform at a standard expected of graduates. This paper reports on insight into the approaches and methodologies used for learning and teaching of the capstone FYEPs. National and international literature outlines a variety of information regarding the capstone FYEPs structures, elements of its assessment criteria, and methodologies of learning and teaching. More specifically, the study seeks to map processes, assessment and supervision practices of capstone FYEPs and to provide a set of guidelines and tools to ensure quality outcomes of capstone FYEPs. This study is intended to promote quality practice amongst supervisors and academics involved in learning, teaching and facilitating capstone FYEPs. A questionnaire was conducted to answer a broad research question: What is the current approach used in learning and teaching of capstone FYEPs? The questionnaire outcomes and a number of common issues, discrepancies and inconsistencies found are outlined in the paper. In supporting its claims, the paper offers some qualitative data to explore contentious issues around capstone learning and teaching. This is pertinent to those involved in the design and teaching of capstone projects.

Keywords: final year engineering projects (FYEPs); learning and teaching; assessment

Snapshot style poster sessions where student teams prepare simple, pinned-up posters that show off in-progress status of their projects are efficient and effective sources of just-in-time design feedback. In the authors' experience, snapshot poster sessions can satisfactorily accommodate up to 30 project teams during a single class period. The intended audience is other students in the class, faculty advisors, professional staff, nearby clients, and interested students not enrolled in the class. Minimal additional preparation time is expected for mid-semester snapshot days. The idea is that project teams continue work on normal project activities for as long as possible, creating poster content in the final day before the session, reusing resources from personal logbooks and project binders. Snapshot poster sessions, scheduled several times throughout the course of a project, provide opportunities for multiple parties to provide formative assessment, share best practices, highlight common struggles, and punctuate common milestones for capstone design projects. To measure the impact of snapshot events, data was gathered from both participating students and instructors using post-event classroom activities, logbooks, and surveys. The data was analyzed to look for patterns in the subject of the feedback (design process, design products, and team processes, and the snapshot experience itself) as well as the source of the feedback (self-directed or peer-directed). The data collection showed that large quantities of feedback were generated about student design process and products while less feedback was generated about student team process. The volume of peer feedback was increased with formal writing prompts. A faculty survey identified high leverage subjects to emphasize in different snapshot events throughout the duration of a project.

Keywords: peer review; design review; capstone projects; formative assessment; just-in-time learning

Teaching students in teams presents challenges. A panel discussion concerning methods for supporting successful teams was held at the 2014 Capstone Design conference. This paper summarizes the main discussions from the panel and interprets those discussions using Self-Determination Theory. Self-Determination Theory addresses the internalization of extrinsic motivators, particularly through the experience of competence, autonomy, and relatedness. The panel members represented diverse areas: engineering practice, medical environments, academic, and military teams. Detailed notes from the panel discussion were distributed to and analyzed by all panel members. That analysis revealed eight research-to-practice findings: promote real world experiences, match teams and projects to empower success, teach students to work in teams, develop leadership for more effective teams, encourage regular assessment of team functioning, promote individual accountability, remediate team dysfunction, and train and monitor team mentors. Each finding is discussed, linked to the literature, and to the elements of competence, autonomy, and relatedness.

Finally, a suggested approach to implementing team work in a capstone class is presented. The approach synthesizes the research-to-practice suggestions, and attempts to describe, model, and scaffold teamwork- and leadership-related professional skills. The panel participants offer the suggestions because of their belief that students benefit from focused teamwork-related support throughout the capstone experience.

Keywords: teamwork; motivation; dysfunction; coaching

Charles Pezeshki and **Steve Beyerlein**   1760–1772   Improving Capstone Design Outcomes and Student Development by Coaching the Client

Although many capstone programs have made progress in involving outside stakeholders as project sponsors, there is much that can be improved by understanding the growth transitions students undergo and how outside professionals can assist in that growth process. While project characteristics and design course activities are catalysts in this development process, coordinated actions by capstone instructors and clients often activate this development. This article explores tools for assessing and enhancing the skills of professionals who mentor capstone teams. Instructor/client coaching is framed around three naturalistic instructor/client/team interaction windows within the arc of a capstone project. These include pre-project scoping, the preliminary design review, and the detail design review. It is up to capstone instructors to recognize exactly what student development opportunities can be unlocked during these interaction windows and to prepare those involved to take advantage of these opportunities. A client assessment rubric is offered for this purpose as are a set of scenarios about common project situations where capstone instructors could coach their clients.

Keywords: sponsored capstone projects; human development; mentoring; coaching the client; spiral dynamics

Jay Goldberg and **Susannah Howe**   1773–1779   Virtual Capstone Design Teams: Preparing for Global Innovation

Global innovation requires collaboration between groups of people located in different parts of the world, and is a growing trend in industry. Virtual teams are often used to manage new product development projects. These teams are similar to traditional teams but are geographically separated and rely heavily on virtual methods of communication (email, Skype, teleconferencing, etc.) instead of regular face-to-face meetings. Experience working as a member of a virtual capstone design team can help prepare students for this growing trend. To begin preparing students for work on virtual teams in industry, we co-advised two virtual capstone design projects with students from Marquette University and Smith College. This paper describes our experience with managing two virtual capstone design project teams across institutions. Presented here are the challenges we encountered, the lessons we learned as a result of this experience, as well our recommendations for others who might want to include virtual project teams in their capstone design courses. We also include retrospective feedback from the students on these teams regarding their perceived value of their virtual team experience to their careers in engineering.

Keywords: virtual teams; geographically-distributed teams; global innovation; capstone design

Clifford A. Whitfield, Robert B. Rhoads   1780–1798   Multidisciplinary Capstone: Academic Preparation and Important
and **Jacob T. Allenstein**   Outcomes for Engineering Practice

The Ohio State University Multidisciplinary Capstone Program provides opportunities for engineering and non-engineering students to participate in an industry-partnered capstone experience through a two-semester course sequence with realistic projects defined by the sponsor and program. The program recently concluded a three-year effort to obtain formalized responses from its industry-partners, program alumni and students who had just finished the multidisciplinary capstone experience. The primary focus was on establishing rankings of the corresponding stakeholder's perspectives to the importance of the program's learning outcomes and relevant accreditation board for engineering and technology criteria, and the program's contribution to the student's preparedness. Key comparisons were made between each of the stakeholders. The results were also compared to the rankings of important knowledge, skills and abilities for all engineering students identified by the Transforming Undergraduate Engineering Education Phase I workshop study; a study conducted by the American Society for Engineering Education in 2013 to develop a strategy for undergraduate engineering education that meets the needs of industry in the 21st century. The data for each survey is provided with key observations and discussions on how the surveys are being used to continuously improve the multidisciplinary capstone program at Ohio State.

Keywords: multidisciplinary capstone; industry needs; industry perspectives; outcomes; assessment; program structure

Ada Hurst and **Oscar G. Nespoli**   1799–1809   Peer Review in Capstone Design Courses: An Implementation Using Progress Update Meetings

Peer review of design progress and artifacts is not very common in engineering design education. Yet, the broader educational literature suggests that the impact of peer (novice) review can be superior to instructor (expert) only review in various ways. This paper describes a systematic implementation of face-to-face peer review in progress update meetings (PUMs) of a management engineering capstone design series of courses. In biweekly PUMs the instructors met jointly with two teams at a time, paired based on topic similarity. Teams took turns presenting to and critiquing each other's presentations and design progress. The format was well-received by students and was successful in increasing the diversity and wealth of knowledge teams could draw from during the meetings. A student survey revealed that students perceived that the regular joint PUMs encouraged them to maintain a steady progress in their design projects, facilitated peer-to-peer sharing of ideas, and were instrumental in helping teams improve on how they communicated their designs by providing multiple opportunities for revisions and refinement.

Keywords: peer review; peer assessment; capstone design; design review

Justine Lawson, Mohammad G.   1810–1818   Getting it Right: The Case for Supervisors Assessing Process in Capstone
Rasul, Prue Howard, Fae Martin,   Projects
Roger Hadgraft and Rob Jarman

Capstone projects represent the culmination of an undergraduate engineering degree and are typically the last checkpoint measure before students graduate and enter the engineering profession. In Australia there is a longstanding interest in and commitment to developing quality capstone experiences. A national study into the supervision and assessment of capstone projects has determined that whilst there is relative consistency in terms of what project tasks are set and assessed, there is not comparable consistency in how these tasks or assignments are marked. Two interconnected areas of assessing process and the role of the supervisor in marking are identified as contentious. This paper presents some findings of a national case study and concludes that whilst further investigation is warranted, assessing process as well as project products is valuable as is the need for greater acceptance of project supervisors as capable of making informed, professional judgments when marking significant project work.

Keywords: projects; assessment; marking; process; subjectivity

Peter F. Rogers and **Denny C. Davis**   1819–1831   Framework for Developing Assessments for Capstone Design Course Outcomes

Capstone design courses offer opportunities to assess significant student learning outcomes specifically relevant to students' careers and useful for program accreditation. A framework for identifying learning outcomes and aligning assessments to various steps in capstone courses is essential for instructional effectiveness and assessment validity. This paper describes a procedure for prioritizing outcomes for assessment in capstone courses with consideration given to needs of the program, students, and society. Outcomes are mapped to natural capstone work products to ensure effective integration of assessments with natural course activities. This framework is constructed around published definitions of desired learning outcomes for engineering graduates and further refined

by a workshop consisting of capstone design instructors at the 2014 Capstone Design Conference in Columbus, Ohio. The paper offers a suggested structure for developing capstone assessments that are applicable to programs across a variety of diverse institutions.

Keywords: capstone; assessments; learning outcomes; engineering; skills; knowledge; abilities

Gene Dixon and **Denny Davis** 1832–1843 Design Reviews for Capstone Courses

Design reviews are required for engineering projects in the workplace, especially where human life and well-being are at stake. However, few engineering undergraduate programs conduct professionally rigorous technical design reviews that prepare students for the demands of the engineering workplace. This article describes the use of technical design reviews in industry and government settings and explains how analogous technical design reviews can be conducted to improve the effectiveness of capstone courses. Criteria are presented for defining and adopting technical design reviews in capstone project courses. These guide the definition of suggested design review questions and scoring rubrics that design educators can use for improving student design, assessing students' design skills, and preparing students for engineering careers. At the same time, by implementing the technical design review, the capstone design course better reflects characteristics of the engineering profession, resulting in student learning and assessment of engineering technical and professional skills that are transferable to the work environment.

Keywords: design reviews; engineering design; industry practice; authentic assessment

Olga Pierrakos, Elise Barrella and **Kylie Stoup** 1844–1859 On the Impacts of Panel-based Technical Design Reviews during the Capstone Design Experience at James Madison University: From Implementation to Mixed-Methods Evidence

In the context of undergraduate engineering education, capstone design is the central and distinguishing activity required by all ABET accredited engineering programs. At James Madison University, the capstone design experience is a two-year experience where students are guided through key phases of the design process: planning and information gathering, system requirements, concept development, embodiment design, testing and refinement, and detailed design. To guide and facilitate students through capstone, Technical Design Reviews (TDRs) with expert panelists are implemented. TDRs occur each semester and focus on the following reviews: (1) System Requirements Review, (2) Preliminary Design Review, (3) Critical Design Review, and (4) Detailed Design Review. This paper presents details about the JMU Capstone Design Model, the TDR process, and evidence grounded in a mixed-methods approach to provide insight into the impacts of TDRs. Significant improvement and growth was measured in capstone documentation as a result of TDRs, in contrast to documentation prior to TDRs. Students' learning and reflections also showcased valuable benefits to TDRs, which have proven to be successful in facilitating both formative and summative assessment during the capstone design experience.

Keywords: capstone design; design reviews; engineering design process; mixed-methods; assessment

Katherine Kuder, Nirmala Gnanapragasam and **J. Paul Smith-Pardo** 1860–1868 Role and Impact of Structural Retrofit Capstone Projects

Robust capstone experiences in civil engineering can be built around modifications to existing structures as opposed to the design of new structures. They require students to not only analyze the systems and identify deficiencies, but also to develop mitigation measures that are feasible and constructible with the existing system. Structural retrofit design projects also expose students to topics that are not covered in a standard undergraduate curriculum. These topics include building codes, lateral loads (wind and seismic), aluminum, timber, and reinforced masonry design, constructability issues, specialized computer programs (Hilti Profis^{TM}, SAP^{TM}) and visualization tools (Solid Works^{TM}, Trimble SketchUp^{TM}) that can convey the design to the client clearly. In our curriculum, students start working on these projects before taking structural design courses and, as a result, spend much of their time learning as they go. Due to the complex nature of engineering retrofit projects, having a good relationship between the department and the project sponsor is important. In this paper we present the students' experiential learning experience through three structural retrofit projects as case studies as well as discuss the technical and professional skills that students develop. We also provide assessment data, which indicate that graduates believe these projects were beneficial in preparing them for professional practice.

Keywords: structural retrofit; constructability; visualization; assessment

Nirmala Gnanapragasam, J. Wesley Lauer, J. Paul Smith-Pardo, Michael Marsolek and **Nathan Canney** 1869–1880 International Civil Engineering Capstone Projects—Benefits, Challenges and Lessons Learned

For the past 27 years the capstone program in the College of Science and Engineering at Seattle University has required all engineering students to complete a nine month long, team based, externally sponsored capstone design project. The Department of Civil and Environmental Engineering has completed nearly 150 projects since the program's inception. In the past decade eight of these projects have been for clients outside the United States of America focused primarily on infrastructure improvement in developing communities. This paper first provides an extensive literature review of international capstone projects completed at other US universities and then describes the international capstone projects completed at Seattle University. Details related to project recruitment, relations with partner organizations, and cultural exchange experiences are provided. Some of the benefits and challenges encountered by the teams reinforce what is reported in the literature, namely, the importance of site visits, dependable local clients in the partnering country, and awareness of local codes, material and construction practices. Assessment results from an alumni survey showed that the participants found the international project experience to be valuable in their professional engineering practice. However, they valued the professional skills they acquired through the capstone project more than the international experience itself.

Keywords: international capstone project; civil engineering capstone

David Alexander, Greg Watkins, Steve Beyerlein and **Scott Metlen** 1881–1891 Processes to Formalize Sponsored Educational Activity Agreements between Industry and Universities Related to Capstone Design Projects

Capstone programs have evolved over the years from small, mostly internally sourced projects with paper-based outcomes to externally funded, industry sponsored projects delivering fully functional prototypes or test fixtures. This increased level of project sophistication and expanded cast of stakeholders has motivated academia and industry to more carefully evaluate the risks and rewards of capstone design programs. This paper surveys institutions across the country that have posted policies and procedures to manage legal as well as contractual issues associated with capstone projects. Findings are discussed in the context of case studies at the University of Idaho and at California State University, Chico spanning the last five years. Both cases illustrate a delicate balance between satisfying needs of university risk management entities and promoting exemplary service learning outcomes. Important issues identified for consideration in industry and student agreements include intellectual property rights, handling confidential or sensitive information, export control, budgeting, overhead rates, billing, indemnification, turnover of project deliverables, timing of project legal documentation, and sign-off by authorized representatives. Points of alignment with activities of the University-Industry Demonstration Partnership are also noted. Issues and best practices outlined in this paper should increase the comfort and satisfaction of all stakeholders involved in externally-sponsored educational projects, including service learning courses in every discipline.

Keywords: sponsored research agreements; contracts; capstone projects; service learning

A Writing Fellows (WF) program has been implemented at the University of Nevada, Reno. The goal of the WF program is to develop targeted writing feedback and instruction for discipline-related communication that leverages existing university resources. Each WF is trained by the University Writing Center (UWC) and serves as a dedicated peer-reviewer who is able to provide constructive feedback on both the disciplinary content and communication aspects of each assignment. This paper reports the impacts of the initial WF implementation in the Mechanical Engineering capstone design course, which has been assessed using a variety of techniques. The assessment generally indicates positive results. In particular, students favor the continuation of the program and find it more helpful than group consultations within the UWC alone. This is due in part to having a WF from the same discipline engaging with students while developing professional writing skills. Self-assessment by the students indicates higher confidence in their communication skills. Preliminary analysis suggests that the writing fellow improved the scores of graded assignments by approximately one-third of a letter grade overall. Assessment efforts also highlight the need for deeper interaction between the WF and engineering faculty.

Keywords: writing; communication; fellows; capstone; engineering

As the culminating experience in ABET-accredited undergraduate engineering programs, capstone design courses might seem an ideal setting for fine-tuning graduating seniors' professional communication skills prior to entering the workplace. Most capstone courses, however, involve team deliverables, including the written project report. As such, ensuring an equal opportunity for writing skills advancement and assessment for all course participants is difficult. But in the mechanical, industrial and manufacturing engineering (MIME) capstone design course at Oregon State University, incorporating an individual writing experience is necessitated by its status as the designated writing-intensive (WI) course for MIME majors. As such, and despite its large size (typically 100–140 students), the course must satisfy the associated university-wide WI requirements—including the specification that individual writing accounts for at least 25% of students' final course grade. Meeting this requirement involves three interwoven course components: (1) An iteratively developed project report in which team members are assigned specific authorial and editorial roles and that involves formative assessment and revision cycles, (2) a metacognitive element involving reflective self-assessment and individual goal setting, and (3) a variety of infrastructural support resources and tools that facilitate production and assessment of student writing. This article describes the MIME approach as a case study for incorporating individual writing in capstone design. The authors recognize that as a solution devised in response to local opportunities and constraints, its "off-the-shelf" adoption at other engineering institutions may be neither appropriate nor viable; the information is being offered solely in the spirit of showing that such an effort is possible and to invite wider cross-institutional conversation on this topic.

Keywords: capstone design; engineering writing; ABET outcome g; writing-intensive courses, writing assessment