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Section I

Special issue

Selected papers from the 2022 and 2024 Capstone Design Conferences

Guest Editors

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Project Management and Systems Engineering are integral components of the Senior Design Capstone Program in Mechanical Engineering at San Diego State University (SDSU). Requirements management, risk management, cost, schedule and scope management, requirements verification and key program milestones including design reviews have been implemented. This paper provides an overview of the program with emphasis on the implementation of Project Management and Systems Engineering practices. Applied experiences from six years of teaching the program involving over 200 projects and 1,000 students are provided coupled with metrics and survey data. Student success rates show 87% of teams report successful project completion. Moreover, 91% of students reported that because of their participation in the SDSU Capstone Program, they received strong preparation for transitioning to industry. Detailed observations and data are reviewed from cross-disciplinary projects including enablers and observations coupled with differences between projects sponsored by faculty, industry, non-profit organizations, government organizations and collegiate competitions. Key course metrics are provided as well as project sponsor and student feedback, with sponsor satisfaction consistently above 79% across all project types. What distinguishes SDSU's Capstone Program is its balanced integration of industry-standard Project Management and Systems Engineering practices with a cross-disciplinary approach that has evolved to include multiple engineering departments, preparing students for the multidisciplinary nature of professional engineering work.

Keywords: systems engineering; project management; engineering design; Senior Design Capstone Programs; Multi-Disciplinary Projects; student success factors

Pre-capstone courses teach students essential skills that will increase their chances of success in capstone design. This work examines the effect of changes in a junior-level lab course on capstone design outcomes. The pre-capstone lab course was altered to emphasize the design of experiments, choosing sensors based on multiple criteria and data acquisition using Arduino-based technology. Textural analysis was used to determine if specific concepts from the pre-capstone course were used and discussed in the final capstone design reports. The number of individual concepts discussed, projects using Arduino sensors, and the prototype completeness score improved as the lab course was changed and refined. The number and sophistication of validation tests improved, and teams were more likely to use statistical data analysis. The results of this work show the benefits of tailored pre-capstone courses in Mechanical Engineering Capstone Design.

Keywords: capstone design; teaching design of experiments; laboratory classes; pre-capstone course

In a Multidisciplinary Design Capstone course sequence, faculty have been integrating the entrepreneurial mindset into the course's learning objectives. The desire to have students identify opportunities to create value, install curiosity about the world and their impact, and connect various topics and material together is of the utmost importance in a multidisciplinary capstone course that includes practical engineering design experience. The Multidisciplinary Design Capstone course sequence focuses on authentic industry sponsored projects that students work on over a two-semester sequence. This paper describes the capstone course as well as the entrepreneurial mindset learning objectives that have been developed and incorporated into the course. These learning objectives are presented as well as their alignment to the ABET Criterion 3 (1–7). Curriculum changes and activities to align with the new learning objectives are presented as well as lessons learned from the faculty. This study looks at student and sponsor/advisor perceptions of the entrepreneurial mindset learning objectives.

Keywords: multidisciplinary; ABET; entrepreneurial mindset

This study investigates differences in collaborative behaviors among undergraduate engineering capstone students through a behavioral sorting methodology. Using the Comprehensive Assessment of Team Member Effectiveness Behaviorally Anchored Rating Scale (CATME-B), 25 students from a senior-level interdisciplinary engineering capstone course sorted collaborative behaviors according to their observed frequency in collaborative experiences. The sorting revealed patterns worth further investigation across technical/task-oriented, process-oriented, and interpersonal/social dimensions of collaboration, with variations

emerging between demographic groups. Technical behaviors showed consistent observation across the sample, while process-oriented and interpersonal behaviors exhibited notable variability. The initial results suggest that collaborative behaviors may be influenced by sociocultural dynamics, with students adapting their engagement strategies in response to identity-related and culturally situated contexts. This preliminary investigation indicates the need for further research to examine how students' perceptions and attitudes toward collaborative behaviors influence their engagement in engineering group work; particularly focusing on the relationships between individual beliefs, group contexts, and behavioral choices. Such understanding could inform theoretical models of engineering collaboration and guide the development of evidence-based approaches to collaborative learning.

Keywords: collaborative behaviors; capstone projects; collaborative effectiveness; collaboration dynamics; CATME; Reasoned Action Approach (RAA)

Improving Outputs from Team Project Work Using Agile Project Management in an Academic Setting 889–900

Emily A. Larsen, Darin Aaby and Charles Pezeshki

Team project work is a key component to many undergraduate courses, particularly in science and engineering fields, as it facilitates teamwork and synthesis of knowledge. However, the work time for these team projects often lacks focus and productivity from students due to lack of ownership, varying levels of commitment between team members, and confusion with how to tackle ill-defined projects. This poses a significant challenge, especially in customer-facing course projects where an external client is relying on a student team to produce a usable output or meet a real need. This paper explores one approach to achieving higher output from class project work by integrating Agile project management in project-based courses. This approach was tested in a mechanical/materials engineering capstone course where students work in teams of 4–6 to complete a semester-long industry project. By adopting this project management tool, the student teams are equipped to self-manage their projects, maximize productivity, and facilitate customer collaboration through frequent prototyping and testing cycles. Results from this implementation, compared with a control group, demonstrate significantly increased productivity and rigor in the capstone course. This paper aims to serve as a resource for instructors of all types of project-based courses seeking to modernize their curriculum, encourage student ownership of projects, enhance outcomes, and alleviate instructor burden.

Keywords: agile; capstone; mechanical; industry; engineering; project management

Is Less More? A Review of Engineering Capstone Time Commitment and Grades 901–910

Aaron J. Rubin

One focus of many engineering capstone courses is getting students to use time efficiently to prepare them for work as an engineer. In Design Clinic, a two-semester engineering capstone at Smith College, a large emphasis is placed on completing tasks rather than total hours worked. Students often struggle with the concept that a large number of tasks to complete doesn't mean they should work more hours than is expected for the class. While time tracking is often used to simulate professional work environments, the relationship between time spent on projects and academic performance remains underexplored. This study investigates whether time tracking correlates with the grades students earn in the course. Over four academic years, 109 students self-reported their weekly hours spent on their projects, which were compared with their semester grades and across the grade components: communication, process, and outcome. The results reveal no statistically significant correlation between time spent and overall or component grades, suggesting that the amount of time worked does not directly influence academic performance in Design Clinic. Potential reasons for the findings are discussed.

Keywords: grading; evaluation; time management; engineering; capstone

Supporting Underrepresented Students in Capstone Design 911–918

Bridget Smyser and Sarah Oman

The biennial Capstone Design Conference utilizes a round-table panel discussion format for many of its sessions that includes a panel of experts and the option for the audience to participate in the discussion. During the 2024 conference, a session was conducted that centered on discussing best practices for supporting underrepresented students in Capstone. In this context, underrepresented students can include BIPOC individuals, international students, neurodiverse and disabled students, LGBTQIA+ students, and other students who make up a small group in a Capstone design course. Although the panel answered several questions, the audience also proposed answers from their experience. The notes from the session were gathered, and ChatGPT was used to summarize the responses. The top ten themes were identified and further grouped into four main focus areas for supporting underrepresented students in engineering capstone courses. These main focus areas included classroom norms and practices; student support and engagement; team dynamics and formation; and diversity, equity, and inclusion (DEI) initiatives. This paper will present the current State of the Art in those areas of published research followed by the overall findings from the panel discussion. A summarized list of key recommendations is stated in the Conclusions based on the results of the panel and audience discussion on their lived experiences as capstone instructors.

Keywords: underrepresented minorities; panel; capstone; teamwork; student support

Expanding the Use of Technical Writer Evaluators for Writing Intensive Course Requirements in Multidisciplinary Capstone 919–927

Sarah Oman, John Parmigiani, Judy Liu and Joseph Piacenza

Oregon State University's College of Engineering uses Technical Writing Evaluators (TWEs) in the grading process of individual reports. In short, TWEs provide technical writing expertise at a part-time hire opportunity, reducing the personnel requirements needed to support capstone grading. This practice began in the School of Mechanical, Industrial, and Manufacturing Engineering (MIME) Capstone Program. Shortly thereafter, the use of the TWEs was expanded into the Multidisciplinary Capstone Program (MCP), an alternative course progression for MIME students and other Engineering majors, as well as another interdisciplinary capstone program within the University's College of Engineering: the Civil and Architectural Engineering (CE & ARE) program. Information regarding the hiring process of new TWEs is presented to encourage other capstone programs to follow suit. This paper outlines the use of the TWEs in supporting extensive written grading requirements and presents the results of distributing their efforts between multiple sections of capstone, and what training was required to normalize the scores between all three evaluators.

Keywords: writing; multidisciplinary; grading; capstone

Using Design Signatures to Make the Invisible Visible: Designing Activities for Design Process Learning 928–946

Jennifer Turns, Reid Bailey, Susannah Howe, Krina Patel, Daria Kotys-Schwartz, Micah Lande, Eli Patten, Nicole A. Batrouny and Cynthia J. Atman

This paper examines how engineering design educators integrate design signatures – visual representations of design processes generated through structured reflection – into their teaching practices. Through analysis of two detailed design cases and systematic mapping of implementation possibilities, we explore how early adopters adapted this emerging pedagogical tool across different educational contexts. The cases reveal educators' decisions, challenges, and observations about student learning as they implemented design signatures in various ways, from short in-class activities to semester-long projects. A morphological analysis synthesizes the space of possible implementations across three dimensions: production choices, timing and frequency choices, and use and reflection choices. This work makes two key contributions: it provides concrete examples of implementation through detailed design cases and creates a framework for understanding the range of possible implementations. These insights can guide both practitioners seeking to adopt design signatures and researchers investigating their educational impact.

Keywords: design signatures; design timelines; morphological charts; active learning; design projects; design teaching

Section II

Contributions in: Diversity, STEM, Engineering Ethics, Demographic Factors, Creativity, Entrepreneurship, Action Research, Peer Instruction, First-Year Students, Major Selection, Leadership, Engineering Identity, Professional Practice, Doctoral Students, Role of Math, Academic Achievement, Persistence, Self-efficacy, Engagement, Fluid Mechanics Modules

exploratory factor analysis and multivariate regression. Four factors emerged as significant: positive attitudes toward entrepreneurship, perceived behavioural control, entrepreneurial education, and the negative influence of social norms. The regression model explains 59.7% of the variance in entrepreneurial intentions, highlighting the role of these factors. Findings reveal that engineering students often lack the skills and confidence needed for entrepreneurship despite showing enthusiasm. A well-structured entrepreneurial education programme can address these gaps by fostering a positive mindset and providing practical skills. Furthermore, governments play a key role in promoting entrepreneurship through supportive policies, reducing risks for startups, and encouraging universities to position entrepreneurship as a viable career path. These efforts can inspire the next generation of entrepreneurs and strengthen public support for entrepreneurial initiatives. This study offers valuable insights for improving entrepreneurial activity in developing regions.

Keywords: entrepreneurship; entrepreneurial education; engineering students; Theory of Planned Behaviour; Southeast Europe; exploratory factor analysis

Action Research in Computer Engineering Education: Enhancing Expository Lessons Through Peer Instruction 1018–1029

Óscar Fresnedo, Adriana Dapena, Francisco Laport and Paula M. Castro

This paper examines the effect of peer instruction in higher education by implementing an action research study. The paper discusses the key aspects of an instructional methodology designed to achieve four educational objectives: (1) to make theoretical lessons more interactive, engaging students in their own learning process in a more active manner; (2) to enhance the understanding of abstract and complex concepts; (3) to foster students' abilities to argue and develop critical thinking; and (4) to enable professors to identify areas where students face the greatest difficulties. The study involves 56 students from a Computer Engineering degree course. The evaluation focused on both academic results and student perceptions in comparison with a traditional teaching methodology. Overall, academics evaluation metrics improved, and the participants in the research showed a positive perception and attitude towards the use of peer instruction as a learning tool in the classroom and considered it a viable alternative for knowledge sharing.

Keywords: action research methodology; active methodologies; computer engineering; peer instruction

Exploring the Relationships between Rejection Sensitivity and Engineering Students' Application to Major 1030–1042

Tyler Milburn and Krista M. Kecskemety

Many competitive engineering programs have academic major application processes that introduce implications for retention in engineering programs. A rejection from a student's first choice of engineering major is a psychological and sociological form of rejection that can influence decision making about navigating engineering attrition pathways. To understand how students engage with social rejection in this context, we quantified rejection sensitivity using a validated questionnaire in 306 engineering students enrolled in a program that required them to apply internally to ranked-choice options of engineering major. Demographic (race, first- vs. continuing-generation status), GPA, and decision-making data were collected and analyzed in their relationships with rejection sensitivity. Rejection sensitivity does not change with race or GPA yet differs significantly with gender and first-generation status (ANOVA, $p < 0.04$), with first-generation women having the lowest scores and the least likelihood to avoid potential rejection. We demonstrate that rejection sensitivity significantly predicts two decision making ''events'' in the engineering major application process (binomial logistic regressions, $p<0.05$), switching pre-major and accepting an offered major. Findings shed light on how rejection sensitivity influences engineering major decision-making and provides insight to engineering educators developing support system for major-changers. Results highlight the complexity of students' decision pathways in competitive STEM fields and reinforce that a 'one-size-fits-all' approach cannot be applied to students undergoing academic major decisions.

Keywords: first-year students; major selection; rejection sensitivity; engineering

Relating Shared Leadership to Academic Team Attributes for Mechanical Engineering Capstone Design Teams 1043–1060

Brian J. Novoselich and David B. Knight

The engineering profession continues to articulate the need for engineers to take more prominent leadership roles to better-inform complex policy decisions and for faculty to support undergraduate engineering students' development of a basic level of leadership understanding. A general lack of empirically tested engineering leadership models may contribute to leadership concepts remaining on the periphery of the engineering curriculum. Several studies indicate that a shared leadership model may be more effective than the historically vertical models for design teams, but little is known about how attributes of design teams relate to shared leadership enactment. This study further develops a model of how engineers lead in collaborative, team-based environments. This quantitative study examines hypothesized relationships between specific academic, team-level attributes and the level of leadership sharing across members of capstone design teams using undergraduate mechanical engineering capstone design team member leadership ratings of each of their team members. The data, collected during the 2014–2015 academic year, represent 45 complete capstone design team totaling 209 students across three research sites. Regression analyses relate social network analysis-derived measures of shared leadership to academic attributes of the team. A selection of team attributes, including team engineering grade-point average, grade-point average diversity, team leadership skills, and team size, related to various aspects of shared leadership within capstone design teams. More specifically, results indicate that engineering disciplinary ability of students, as measured by engineering course GPA, and student self-perceptions of their leadership skills relate to the shared leadership networks of capstone design teams. This study expands an empirically tested model of how engineers lead for undergraduate engineering student design teams. How capstone design teams are formed may play a role in the type and level of leadership sharing that occurs during a student capstone design project.

Keywords: shared leadership; engineering leadership; team effectiveness; social network analysis

The Social, Cultural, and Material Contexts of Doctoral Engineering Students' Research Experiences for Professional Practice Preparation 1061–1085

Eric A. Holloway, Kerrie A. Douglas, William C. Oakes and David F. Radcliffe

Engineering educators put great faith in research experiences to prepare graduate students for professional practice, yet we know little about how the characteristics of these experiences shape them. This investigation addresses this gap by examining how different research experiences affect the professional abilities of 451 doctoral engineering students from multiple institutions. Research questions focused on the kinds of research experiences, the measured differences in experiences, and what those differences indicate about doctoral students' preparedness. It offers a Conceptual Framework that categorizes the important aspects of graduate engineering students' research experiences related to their social, cultural, and material significance to professional practice. Based on this framework, we surveyed 451 doctoral engineering students about their social, cultural, and material research experiences related to professional practice and clustered students into groups based on their responses. Students also completed the Research Experiences Instrument (REI), a measure of opportunities for students in their research experiences to practice being a professional. The combination of REI and self-report questions identified deficiencies in research settings and students' professional development improvement needs. Strategies that faculty, administrators, and students can implement to increase graduate students' opportunities for professional practice are provided.

Keywords: assessment; doctoral engineering students; professional practice; research experiences