Guest Editorial Special Issue on Project-Based, Senior Design, and Capstone Courses in Engineering Education

SENIOR design and capstone courses are an integral part of any engineering curriculum around the world. These courses perhaps provide the only opportunity for students to apply the theoretical knowledge and technical skills they have acquired throughout the engineering degree. Moreover, they are often the (sole) environment in which students get some of the professional and transversal skills too. In addition, such courses present a great degree of nonuniformity since the students engage in projects of different nature (e.g., research oriented versus application oriented). Furthermore, not only do these courses prepare students for real-life engineering practice, they also serve as a major component in measuring program outcomes. The survey conducted over two decades ago by Todd *et al.* [item 1) in the Appendix], which collected responses from 360 departments across 173 schools, highlighted many of the issues related with capstone courses that are still relevant today. Such issues include course format, different degrees of faculty involvement, and project completion requirements. Indeed, all points highlighted thus far emphasize the importance of adequately designing and assessing capstone design courses.

Modern studies have highlighted the unique role of capstone design projects (CDPs) in developing students' technical skills [item 2) in the Appendix]. In a CDP course, students apply all the knowledge and skills they have acquired throughout their undergraduate studies. Various works on good practices and methodologies for management and assessment of capstone design course exist in the literature—in addition to their role in program accreditations, for example, by ABET [items 3) and 4) in the Appendix]. In [item 5) in the Appendix], a typology for Computer Science Engineering CDPs supervision is proposed. The study includes the development and validation of an instrument to determine different approaches of supervision. Chen *et al.* [item 6) in the Appendix] present the meetingsflow (MF) method and study its effect on teams undergoing their CDPs. Empirical proofs are provided to confirm that MF enhances team collaboration and balance contributions among team members. Nevertheless, MF is found to have little or no influence on team cohesion.

The goal of this special issue is to contribute to the advancement in engineering education through empirical investigations in project-based, senior design, and capstone course developments. The special issue presents modern best practices that evaluate aspects of design, implementation, and evaluation of project-based, senior design, and capstone courses in engineering education. The special issue scope includes contributions to education in electrical and electronics engineering, computer engineering, computer science, and other fields within the scope of interest of IEEE.

This special issue presents the following six different contributions within the defined scope.

1) *Using Continuous Peer Evaluation in Team-Based Engineering Capstone Projects (A Case Study):* This article presents a method to fairly assess the individual team member's contribution toward the team effort.
2) *Supporting Self-Directed Learning in a Project-Based Embedded Systems Design Course:* This article shares the learning ecosystem of a project-based embedded systems course, identifying course elements that support self-directed learning and how assignments guide students toward becoming adaptive experts.
3) *Use of a Cornerstone Project to Teach Ill-Structured Software Design in First Year:* This article presents a first-year programming course that is redesigned with a large, open-ended robotics project. The course design aligns with best practices for promoting the development of students' self-efficacy in solving ill-structured software design problems.
4) *Engineering Education for Sustainable Development: The European Project Semester Approach:* This article presents an analysis of the extent to which sustainability is present in the syllabi, project briefs, report templates, and student final reports of the three Iberian European project semester providers over a five-year period.
5) *Idea Generation Practices in a Biomedical Engineering Capstone Course:* This article examines ideation practices of biomedical engineering students in a capstone design course during a designated team ideation session and provides recommendations for structuring idea generation.
6) *The Influence of Entrepreneurial Mindsets on Student Design Problem Framing:* This article presents an increased understanding of the influence of a project-based multidisciplinary design and innovation course on students' engineering design thinking, specifically regarding problem framing.

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CDPs continue to play an important role in engineering education. Future work can include studies on how project-based, senior engineering design, and capstone courses influence student development in design professional skills, and project management and interpersonal skills. In addition, future interest will be on how industrial sponsored projects and industry partnerships help students develop design and professional skills. Moreover, multidisciplinary projects that demonstrate creative models and technologies continue to be of interest to engineering undergraduates. Aspects like the integration of ethical, legal, and societal issues into senior capstone courses are longstanding requirements by ABET accreditation and will be retargeted with investigations adopting the new set of SOs within the ABET General Criterion 3. Furthermore, future investigations can include assessment of complex learning outcomes, role of capstone courses in community service and civic engagement, use of capstone courses in satisfying accreditation requirements, preparation of students for their capstone experience, and presenting best practices and roles of engineering competitions and undergraduate research conferences in the scholarship of teaching and learning.

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APPENDIX
RELATED WORK

1) R. H. Todd, S. P. Magleby, C. D. Sorensen, B. R. Swan, and D. K. Anthony, "A survey of capstone engineering courses in North America," *J. Eng. Educ.*, vol. 84, no. 2, pp. 165–174, 1995.
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3) S. Beyerlein, D. Davis, M. Trevisan, P. Thompson, and K. Harrison, "Assessment framework for capstone design courses," in *Proc. Amer. Soc. Eng. Educ. Annu. Conf.*, 2006, p. 3.
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5) C. D. Pérez, A. J. Elizondo, F. J. García-Izquierdo, and J. J. O. Larrea, "Supervision typology in computer science engineering capstone projects," *J. Eng. Educ.*, vol. 101, no. 4, pp. 679–697, 2012.
6) C.-Y. Chen, Y.-C. Hong, and P.-C. Chen, "Effects of the meetings-flow approach on quality teamwork in the training of software capstone projects," *IEEE Trans. Educ.*, vol. 57, no. 3, pp. 201–208, Aug. 2014.

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