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The goal of the 2016 Capstone Design Conference held in Columbus, OH was to build upon the success of previous conferences (2007 and 2010 in Boulder, CO, 2012 in Champaign, IL, and 2014 in Columbus, OH) and expand the community of educators, students, and industry members engaged in discussing, analyzing, and improving capstone design education. Sessions at the 2016 Capstone Design Conference were designed for vibrant sharing of ideas and experiences across the capstone community via interactive panel sessions, poster session socials, hands-on workshops, and other formal and informal networking activities. This editorial discusses conference planning, structure, and feedback. Technical papers that follow in this issue document scholarship surrounding noteworthy capstone course innovations. Most of these began as four page peer-reviewed papers included in the conference proceedings.

Keywords: capstone design courses; design pedagogy; capstone conferences; capstone community

Capstone design courses are common in engineering design programs, but they vary substantially across institution and department. The goal of the decennial capstone design survey initiative is to capture data from capstone design courses every ten years to identify current practices and changes over time. In keeping with its predecessor surveys, the 2015 capstone design survey included questions on course logistics, pedagogy, evaluation, faculty, students, projects and teams, expenses and funding, and sponsors. The 2015 survey captured data from 522 respondents at 256 institutions, documenting the variety of implementation strategies for capstone design programs across the U.S. These data include quantitative and categorical responses about current practices and open-ended responses about respondent experiences and opinion. This paper presents the current state of capstone design education, draws comparisons across disciplines, and highlights changes within capstone design practices over the past 20 years. These surveys and the data gathered therein are an important first step in understanding, assessing, and ultimately improving engineering capstone design education.

Keywords: capstone design courses; capstone projects; capstone pedagogy; decennial survey

During the project selection phase in a capstone course, it is often the case that some projects are more popular than others. To understand the factors students consider when selecting a capstone project, Mechanical, Biomedical, and Electrical engineering students were surveyed. An initial survey in 2015 of 83 participants rated how important each of 14 pre-determined factors were in their recent individual project selection process. The data was analyzed to determine the relative importance of the factors. A second survey was conducted in 2016 with 69 participants using a slightly modified set of 18 pre-determined factors. The results of these two surveys were consistent and showed that a majority of students are taking into account a diverse range of factors when they select their capstone projects. The top rated factors in both surveys relate to three main areas: (1) to gain experience in a particular field or technology, (2) the desire to work with industry partners and (3) the quality and completeness of the information about the particular project available at bidding time. These results are used to identify some specific actions that can be taken to significantly increase the chance that students have a positive educational experience in capstone courses.

Keywords: engineering capstone design; project selection; survey; student opinion

As the number of international undergraduate students in U.S. universities grows, more students will be required to work on multicultural Capstone teams. The increase in multicultural teams is an opportunity to provide student experiences in diverse teams with their associated increase in successful, innovative solutions, if managed properly. A total of 237 previous Capstone design project teams were studied to determine relationships between the number of international students on a team and outcomes such as prototype completeness and writing grade. This database provides objective information to investigate the accuracy of anecdotal observations and to develop strategies to improve student outcomes. Other factors such as previous experience with group members, language proficiency, and whether or not a team was student formed were also investigated. Results show that international students tend to perform better on student formed teams, and that their ability to create a student formed team tends to correlate highly with English language proficiency. The results of this investigation provide insight for mentoring actions to improve student outcomes and to provide positive experiences for all students while remaining sensitive to cultural differences.

Keywords: international students; team formation; multicultural teams; capstone design

Cultivating the relationship between industry representatives and capstone instructors is an important and often overlooked first step in running a successful capstone program with externally-sponsored projects. In this article, a problem scoping philosophy and supporting methodology is presented for generating shared understanding about the project starting point and the intended project deliverables. The article traces steps from initial project dialogue with the client, to current technology assessment, to assessment of available resources, to management of uncertainty within the arc of the project, and finally to drafting of a project scoping document that is suitable for inclusion in a class-wide portfolio of capstone project options. The methodology is derived from the NASA rubric for Technology Readiness Levels (TRLs). The resulting problem scoping template has been used successfully by the authors to secure over $2M in funding for capstone projects over the last fifteen years. Statistics about the success of project descriptions with different TRL levels and resource requirements are presented. The approach outlined here is especially well-suited to projects with client-approved deliverables. It can be used in conjunction with a negotiation for early agreement mindset to settle on an accessible problem scope which faculty and students can use to sort out alternative project options as well as provide a robust starting point for each project team.

Keywords: capstone project scoping; technology readiness levels; resource assessment

With the expectation that engineering students ought to be prepared to adapt to a continuously evolving workplace environment to solve the complex problems of the future, engineering educators ought to also adapt and provide innovative learning environments that support not only technical agility, but also psychological agility to support the development of our students. Senior design and capstone courses serve as ideal contexts to support engineering students with this preparation. This paper describes how a senior design course was transformed not in content, but in the classroom values/culture, reward structures, and the learning environment to encourage mastery learning though effort contingencies, grit and perseverance, collaboration, and empowerment. Designed as a pre-test post-test control group design, a set of psychological constructs (grit, sense of belonging, achievement goal orientation, self-efficacy, impulsivity) were administered to a treatment group and a control group to investigate effects of the educational innovations. Effect sizes reveal moderate to high practical significance comparing the treatment and control groups. Psychologically-grounded strategies and important implications for all engineering educators are detailed in this paper.

Keywords: senior and capstone design; goal orientation; grit; effort contingent learning; belonging; self-efficacy

Capstone design is the "bridge" from school to industry. It is important that this engineering experience is rich in the creative approaches which are valued there. In particular, the capstone class should model the need for exploring divergent solution paths, for listening to alternative opinions, and for stepping back from a problem. Skills in these creative areas typically are not emphasized in the rest of an engineering curriculum. At the 2016 Capstone Design Conference, we participated in a panel on "Encouraging Creativity in Capstone Design." The ideas presented were based on our own experiences in using creativity techniques in design classes. This paper shifts down to the roots of those discussions, describing our individual efforts in applying those creativity techniques. We conclude with a list of situational options, for other practitioners to use in their design classes.

Keywords: creativity; convergent thinking; divergent thinking; concept generation; idea fixation

Capstone design courses have traditionally provided students with a culminating, project-based experience that fosters the integration of prior academic learning, a connection with industry, and by nature of that connection with industry, preparation for employment. However, in today's competitive global economy, where organizations gain value from the innovativeness of their employees, capstone design courses that integrate innovation and entrepreneurship might better prepare students for employment. There are multiple examples of capstone courses that integrate innovation and entrepreneurship, but it is unclear how and to what

degree most capstone instructors integrate different entrepreneurial elements into capstone design. To better understand how and to what degree entrepreneurial elements are integrated, an explanatory multiphase mixed methods design was used, involving the collection and analysis of quantitative survey data, qualitative survey data, and post-survey interview data. One hundred and thirty-eight capstone design faculty were surveyed with an instrument designed using the entrepreneurial capstone practices described by Shartrand and Weilerstein. The quantitative and qualitative data illustrate the extent to which faculty incorporate different entrepreneurial practices in their capstone design courses, how important faculty believe it is to increase different entrepreneurial practices in capstone design, the challenges (perceived and actual) to implementing entrepreneurially focused Capstones, and how faculty members' understanding and experience of entrepreneurship impacts their integration of entrepreneurial elements into capstone courses. These findings are useful for faculty and administrators interested in integrating entrepreneurial elements.

Keywords: capstone design; entrepreneurship; innovation; curriculum

Design is a human activity that encompasses a broad array of tasks. In engineering design, individual efforts can be aggregated into teams to maximize collective progress. Effective teamwork, however, requires extensive management, organization and communication. Furthermore, modern challenges encompass complicated multi-disciplinary problems with faster schedules, fewer resources, and greater demands. Design, as a process, can be dissected into characteristic phases. Within each phase, design solutions are gradually developed. Technological tools have prioritized the structured analyses of the detailed and final design phases and have proven to be powerful multipliers for effective design efforts. It has long been the case, however, that major commitments of intangible resources are made as a result of efforts in the less emphasized *earlier* phases. These commitments and lack of modern toolsets for requirement development and conceptual design activities materialize as major sources of design pitfalls, both in industry and on student design projects. This paper presents a digital Ecosystem for Engineering Design Learning as a comprehensive, yet flexible, framework for capstone design teams. The digital Ecosystem has been developed as a feasible technology to bolster student information management, teamwork, communication, and proficiency in fundamental design principles, and as a technology capable of alleviating rework and process-related productivity interruptions. Its primary innovation, for capstone applications, is the ability to assess design work automatically against the design process, as well as against ABET compliant learning objectives, and provide prompt advisories in case of design oversights. The digital Ecosystem is compared to tools for project management, team communication, and requirement management.

Keywords: design process; design software; project management; team collaboration; ABET learning outcomes; engineering education

Engineers and industrial designers have different approaches to problem solving. Both place heavy emphasis on identification of customer needs, manufacturing methods, and prototyping. Industrial designers focus on aesthetics, ergonomics, ease of use, manufacturing methods, and the user's experience. They tend to be more visual and more concerned with the interaction between users and products. Engineers focus on functionality, performance requirements, analytical modeling, and design verification and validation. They tend to be more analytical and more concerned with the design of internal components and product performance. Engineers and industrial designers often work together on project teams in industry. Collaboration between the two groups on senior capstone design projects can teach each to respect and value the unique contributions each brings to the project team, result in improved design solutions, and help prepare students for future collaboration in industry. Student feedback and lessons learned by faculty and students from a ten-year collaboration between engineering and industrial design students from Marquette University and the Milwaukee Institute of Art and Design, respectively, are presented. Students learned to communicate with people in other disciplines, appreciate the complementary skills of each discipline, and value different approaches to problem solving.

Keywords: industrial design; multidisciplinary teams; capstone design; design collaboration

Capstone design courses are pivotal in engineering curricula, and understanding and assessing the resultant learning is critical to both researchers and practitioners. While current scholarship does provide tools for such assessments, most are based on outcomes derived through research with faculty, administrators, and various industry stakeholders. As a result, students' self-reported learning gains have been largely overlooked. Addressing this gap, this paper presents a qualitative thematic analysis that explores student perceptions of capstone learning. Drawing on 50 semi-structured interviews with 31 students from three different institutions, we describe four emergent themes: (1) Engineering Design Skills; (2) Teamwork and Communication; (3) Self-directed Learning Skills; and (4) Development of an Engineering Identity. These themes are generally consistent with current outcomes identified from other sources, but students' discussions also highlight areas of personal development that move beyond acquisition of technical and professional skills. That is, students' perceptions of their own learning in capstone reflect not only those outcomes currently desired by various stakeholders and accreditation bodies, but also outcomes that might be more subtle and less tangible than those demonstrated via traditional assessment approaches. Thus, we argue that in order to more meaningfully support student growth, both technical and professional, capstone faculty should incorporate opportunities to actively promote and provide evidence for the kinds of critical reflection that students engage in throughout the course.

Keywords: design learning; capstone design; engineering identity; professional development

Reflection is an implicit professional skill for engineers that is embedded within the engineering curriculum, but rarely explicitly taught to or discussed with students. A sample of 114 students enrolled in an engineering capstone design course and 73 engineering educators attending the 2016 Capstone Design Conference were asked, "How do you define reflection?" to shed light on how engineering education stakeholders perceive reflection. Responses were coded utilizing three categorical definitions of reflection: (1) reflection-on-action, (2) reflection-in-action, and (3) reflection-then-action. Results demonstrate that nearly half of all student and educator participants in the sample view reflection strictly as an opportunity to look back on an action. The remaining two categories of reflection, varied between educators and students with a larger percentage of students viewing reflection as a process and a larger percentage of educators seeing reflection as impacting future actions. These findings suggest that a slight disconnect exists between the beliefs of students and engineering educators. Both groups could benefit from a better understanding of what reflection is, which could result in an appreciation gain for regular practice of reflective activities.

Keywords: reflection; engineering design; perceptions

This study focuses on the two main design approaches applied to the guidance of student product development during capstone design courses through a comparison of two major approaches: traditional design process (TDP) and design thinking (DT). The

objective of this paper is to discuss the impact of these design approaches on student activities, outcomes, and learning. Our research, conducted over three years, compared two courses offered at the same university, one applying TDP and the other DT. The research method consisted of three phases: (1) a comparison of the course structures and materials; (2) an analysis of deliverables from 50 design projects developed by 274 students, which was based on documentation and prototypes; and (3) a quantitative survey of the students. Results show that the DT-based course characteristics, such as extended time dedicated to prototyping cycles, limited the possibility of addressing some of the TDP methods (e.g. Quality Function Deployment) in the course timeframe shared by the two approaches. Results also suggest that, despite the shortcomings related to documentation, the DT-based course led to more innovative prototypes when compared to the TDP-based course. It was also notable that the DT course led to increased student self-efficacy in terms of innovation and increased technical knowledge. The results of this study are applicable for supporting the selection of design approaches and the definition of course activities in capstone design project courses.

Keywords: engineering design education; capstone design course; new product development process; design thinking

Though university education is part of the service economy, there have been limited service-oriented studies on university engineering courses. Those focused largely on Kano's basic and performance needs. We used Axiomatic Design to identify two broad classes of Kano's excitement needs for engineering courses: emotional and sensory input. These needs were found to be common elements in extraordinary engineering classroom experiences. We created prototype Functional Requirements (FRs) and Design Parameters (DPs) that a course designer can use to support the insertion of these Kano excitement needs into an engineering course. We redesigned a sophomore-level open engineering course at KAIST (Korea Advanced Institute of Science and Technology). The new design was implemented and evaluated in a class with 109 students. There were statistically significant improvements in the official course evaluation scores and a separate satisfaction survey. Unusual written communications were received from about 7% of the course students. The results were replicated in subsequent semesters. The use of these broad classes of excitement needs appears to meaningfully increase student satisfaction in engineering courses. We hope that the design guidance developed can also be used to insert excitement needs into emerging learning approaches such as inverted classrooms, project based learning and MOOCs.

Keywords: engineering education; Axiomatic Design; service experience; service-oriented design; engineering of education

A multi-section mechanical engineering sophomore design course was flipped to engage future engineers in interactive online learning modules and pre-assessments prior to hands-on collaborative lab sessions. A mixed methods approach was used to achieve our objectives to capture and understand student experiences with course online and in-lab components, and their impact on student self-reported comfort with flipped delivery. Responses from 158 students to a course exit survey demonstrated high comfort with the flipped delivery paired with positive online and in-lab experiences. The strongest positive predictors of comfort determined by factor analysis and block-wise regression were self-reported investment in learning as part of student self-regulation, and the effectiveness of course online learning modules. The strongest predictor of discontent with flipped delivery was associated with unanswered questions upon completion of online learning modules. Qualitative analysis of student responses to three open-needed responses supplemented quantitative results to demonstrate that although student own estimation of sufficient self-regulation for succeeding in the flipped classroom was very high, their self-regulatory behavior was complex, developing and not as efficient as readily presented in their responses to the Likert scale questions. Findings are discussed in connection with the flipped design/development, and implications and recommendations for engineering education.

Keywords: engineering design; flipped classroom; instructional methods; mechanical engineering; pedagogy; student experiences

Location decisions represent an integral part of firms' strategic planning process. Because these decisions have a significant impact on the organization, location analysis is a recurrent topic on operations management courses. In this study, we posit that students enrolled on such courses should experience location decisions actively. To this end, this paper proposes an activity that adopts a student-centred approach. The main purpose is for students to acquire the required technical skills to deal with location decisions. Furthermore, the activity is designed in such a way that it also helps students develop some of the soft skills that operation managers should possess, such as teamwork and digital skills. The activity mimics a real-life situation, with students asked to decide where to locate a specific new public service in the city of Barcelona, Spain. This activity was part of a course on operations management, included in the master's degree in engineering management and production systems taught at the Universitat Internacional de Catalunya. The results suggest that the proposed project-based activity helps students to improve relevant skills needed by project managers. By providing students with the opportunity to take part in a location decision that simulates a real-life situation, the activity enhances students' experience-based learning.

Keywords: Project-based learning; technical skills; soft skills; operations management; location selection

Game-based learning has become a popular topic in all levels of education. A number of computer games have been developed to teach different subjects such as mathematics, English language, medicine, and music. This paper presents the first study that proposes the development of edutainment games to teach data mining techniques with the scope of game-based learning. The aim of this study is to provide an environment that is both fun and enables the achievement of learning goals in data mining training in computer engineering. An escape game called Mine4Escape, which consists of different rooms to teach different data mining techniques (classification and association rule mining), has been developed for individuals at the undergraduate and post-graduate levels. The advantages of the proposed approach are discussed in comparison with traditional data mining training. In addition, this paper describes a dynamic scoring system designed for game-based learning. Finally, an experimental study was carried out to evaluate the performance of our learning environment by analyzing feedback received from a test group consisting of 39 undergraduate and graduate students in computer engineering. The findings from the questionnaire show that it is possible to enhance knowledge acquisition about data mining via the game-based approach. However, the degree of learning interest and information acceptance changes according to students' age, gender, educational level, and game habits.

Keywords: game-based learning; data mining; education; computer engineering

The functionality and complexity of modern electronic systems increases every year and poses new challenges not only to the industry, but to universities as well. Due to such a rapid development of complex electronics devices and systems, university lecturers and professors are forced to deliver more advanced projects based on teamwork. In order for the students to accomplish projects successfully, university professors should have knowledge and practical skills in social psychology, project management, successful team building. This article discusses an original and interactive successful team building method, called "Puzzle"

method—applicable with a self-assessment test, based on M. R. Belbin methodology. This team building method has been tested and applied for four years in Vilnius Gediminas Technical University Faculty of Electronics, accomplishing VLSI chip design projects. Data collected within four years from 64 students indicates, that the most successful projects were carried out by teams consisting of dominant Chairman, Implementer, Completer-Finisher, and Specialist team roles, and as many as 84.4% of the surveyed students (26.6%—well, 57.8%—excellent) positively accepted a synergy of the team that carried out the project.

Keywords: electronics engineering education; integrated circuit (IC) design; project-based learning (PBL); interactive learning methods; team building in education

The term *sustainability* means using methods, systems and materials to meet the needs of the present without compromising the future. Even with the prevalence of the term and its wide use across disciplines, there has been little effort to formulate a quality measurement framework in tertiary education based on the values and characteristics of sustainability. The framework that we present here is the Sustainability of Technical Education (SoTE), where *sustainability* is defined as the ability to continuously improve without reducing the capacity to endure. The SoTE consists of criteria, measures, indicators, and a set of aligned analytic rubrics that aid the calculation of different indicators including a one main indicator called the Sustainability Indicator. In this paper, we present the need for a focus on sustainability in higher education for continuous improvement and fiscal purposes, present the SoTE criteria and indicators, and present the results and analysis of a pilot study conducted at a private, non-profit university in the Gulf Cooperation Council (GCC) Region. The paper concludes with a discussion of the usefulness of the SoTE for continuous improvement and for collecting and providing evidence for quality assurance and accreditation organizations at programmatic and institutional levels.

Keywords: technical education; philosophy of engineering education; sustainability; accreditation

In this paper, we build on the idea that specialized instruction improves the overall quality of CAD documents by guiding students into selecting the most suitable modeling strategies and approaches. To this end, automatic assessment tools can be used to detect errors and provide feedback, thus relieving instructors from routine checks and allowing them to address quality errors and modeling aspects of higher semantic level. A representative commercial Model Quality Testing (MQT) solution was selected as a case study to determine whether these tools may become automated assistants for student evaluation and feedback. As a result, a new taxonomy of modeling aspects that can be automatically checked is proposed. We claim that current MQT tools can supplement the learning of quality concepts, but require significant tuning and only provide limited testing and tutoring capabilities. Extending the capabilities of these tools (through macros or dedicated API's), or even developing entirely new MQT tools specifically aimed at instruction purposes, is an essential requirement to develop automated teaching-assistants based on MQT techniques.

Keywords: CAD assessment; CAD model quality; model quality testing

Online laboratories have changed the way of assessing students' laboratory work (lab work). Traditionally, students' lab work is mainly assessed by their reports after the experiments, with their attendance considered as well. However, whether the students are actually engaged in experiments and how they perform their assignments are difficult to be traced individually, especially for the case of a large number of students. In this paper, a multi-criteria method for assessing students' lab work based on online laboratory is proposed. Different from the hands-on labs, the online labs are able to trace and store more students' activities automatically. Apart from the quality of the lab reports, the experimental data collected from the database of the online laboratory as well as the snapshots of experimental steps are also considered. Therefore, judging criteria of lab work assessment can be extended to a higher standard, improving the assessment of student learning with much more objectivity based on lab work related information rather than lab reports only. The paper takes Wuhan University (WHU) as a case study, where students in engineering are using Networked Control System Laboratory (NCSLab) as a tool to conduct experiments for their laboratory sessions. Generalized from the practical teaching, the new assessment method is proved to be useful to judge students' performance during the online experimentation.

Keywords: engagement; engineering education; lab work assessment; online laboratory

Current research based on positive results and obtained experience of a previous publication has developed a training course of metrology based on sustainable characteristics such as remote control freeware applications, share of valuable resources, distance learning methodology and active participation of the students. This is based on a remote control operation using special software, with a real CMM. Although the CMM was placed at the University of Zaragoza (Spain), ten students from Greece, with the valuable help of a remote control freeware application, participated in real time measuring process from their own computers under the supervision of two instructors. The results of the remote operation of the CMM were very successful. A feeling of responsibility for using a remote piece of equipment and the extra care that the students should prove created a more stimulating learning environment. Moreover, according to the students' opinion, the process as a whole was impressive and provided a unique experience. More effort has to be made in order to increase the number of the participants and the number of the used pieces of equipment.

Keywords: sustainability; distance learning; remote control; educational-resources optimization; active methodologies

The current study analyzed how learning resources and human aggregates moderate the effect of intrinsic motivation on the imaginative capabilities of undergraduates. The differences between the moderation models of engineering and science majors were also compared. We administered a survey at seven universities across different regions in Taiwan. Our participants were divided into two groups: the first group consisted of 473 science majors, whereas the second group consisted of 478 engineering majors. Structural equation modeling was used to test all the proposed hypotheses. The results demonstrated that imaginative capabilities became highest when students had high intrinsic motivation, learning resources, and human aggregates. The major difference between the engineering and science groups was the moderating effect of intrinsic motivation and learning resources on initiating imagination. In other words, the initiating imagination for those engineering students who are insensible to learning resources was strongly stimulated when their intrinsic motivation remained high. The other critical difference was the moderating effect of intrinsic motivation and human aggregates on transforming imagination. In other words, transforming imagination for those engineering students who are insensible to human aggregates was strongly stimulated when their intrinsic motivation remained high. Practical implications of the study are discussed and research limitations are explained.

Keywords: engineering education; human aggregates; imaginative capability; intrinsic motivation, learning resources; science education

In this paper, we discuss a vision and the model on how it is possible to introduce STEM** into a single Computer Science (CS) course to educate students at the High School level. We present our approach at four levels: (i) as a conceptual model; (ii) as a framework that gives more information about the conceptual model, (iii) as a process-based vision that is close to the implementation level; and (iv) as two Case Studies that outline the implementation and use aspects. The essence and novelty of our approach is the seamless integration of the essential attributes of STEM-driven and CS-oriented content with the STEM pedagogy features. The use of meta-programming as the implementation technology enables to achieve that though the pre-designed Smart Generative Learning Objects, though we discuss those aspects only fragmentally. We also present an evaluation of the approach from the methodological and pedagogical perspectives, by describing both advantages and limitations.

Keywords: STEM-driven CS education; robotics; process-based model

Early exposure to engineering research and design experience is crucial for students as they enter college. However, this has been limited to the secondary school curriculum, as the majority of secondary school teachers lack the engineering background and experience. Addressing this challenge, this paper presents an engineering research experience program that took place over a span of three years to better prepare 36 secondary school teachers with support from 7 engineering faculty members. This program provides the teachers a broad overview of engineering design enhances their hands-on design abilities, and educates them to translate their learnings from engineering design experiences to lesson plans for their respective classrooms. Through the numerous feedback surveys, reflection sessions, lesson plans designed, outreach and dissemination activities, it was evident that 36 participant teachers were able to gain a better understanding of engineering design, enhance their respective classroom instructional modules, and improve their overall teaching effectiveness in secondary schools.

Keywords: engineering fundamentals; K-12 outreach; project-based-learning; secondary-school curricula; teacher education