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- Ahmad Ibrahim** 1145 Editorial
- Cory Brozina, Andrew Katz and Aditya Johri** 1146–1160 Taking Stock: Analysis of IJEE Publications from 1996–2020 to Examine Impact and Coverage of Topics

In this paper, we present findings from analyses of papers published over the past 25 years (1996–2020) in the International Journal of Engineering Education (IJEE). Our goal was two-fold: (1) to understand the *impact* of papers published in the journal as measured by citations, and (2) to understand the *coverage of topics* over time. To understand impact, we qualitatively analyzed abstracts of articles with at least 30 citations each (N = 218) and to understand coverage of topics we used the Scopus database to download abstracts of all available articles (N = 3,173) published in the journal between 1996–2020. After data cleaning 2,960 articles were analyzed using text network mapping. In terms of impact, the topics that have been cited the most include ways of teaching, learning styles, new technology applications, PBL, and engineering design. The overall topical coverage reflects these findings and shows these same themes were consistently popular over the past 25 years. Major changes over the years have been an increase in attention to learning processes, first-year students, and teamwork.

Keywords: citation analysis; bibliometric analysis; impact analysis; topical coverage

- Ning Fang** 1161–1173 A Non-Parametric Statistical Analysis of the Relationship Between College GPA and ACT Scores for First- and Continuing-Generation Engineering Undergraduates

A significant portion of college students are first-generation students – whose parents' highest level of education is a high school diploma or less, or whose parents have never enrolled in postsecondary education. The present study investigates the relationship between first- and continuing-generation undergraduate engineering students' college graduate point average (GPA) and ACT scores across all four years of undergraduate study, rather than solely the first year. ACT (American College Testing) is a standardized test administered by the College Board and widely used for college admission in the U.S. The data employed in the present study were collected from a 4-year public research institution in the U.S., involving 6,683 student records in recent three academic years. These student records included 977 (14.6%) records for first-generation students and 5,706 (85.4%) records for continuing-generation students. Based on the results of normality tests, non-parametrical statistical analysis was performed in the present study. It was found that in general, the difference in college GPA between first- and continuing-generation students is not statistically significant, while the difference in ACT scores between first- and continuing-generation students is statistically significant. ACT scores are statistically significantly different among all three sub-groups of first-generation students (i.e., those with high, medium, and low college GPA) in all three academic years involved in the present study.

Keywords: first-generation; continuing-generation; engineering undergraduates; college GPA; ACT scores; non-parametric statistical analysis

- Monica Quezada-Espinoza, Angeles Dominguez and Genaro Zavala** 1174–1185 Academic and Professional Relevance of Physics: Comparing Perceptions of Engineering Students from Mexico and Chile

Research about the perception of engineering students regarding the relevance of physics could explain the factors that influence their learning and retention in the engineering curricula. In the present study, we investigate students' perceptions of physics' relevance by comparing results by country, student semester, and gender. This is a quantitative comparative study between engineering students from Mexico and Chile. A total of 1,323 engineering students enrolled in physics courses in two private universities from those countries in their first and third semester responded to an eleven-item 5-Likert scale-type statements survey. Results showed that students in their first semester perceive the importance of physics more positively than students in their third semester. In general, students in the Mexican university have higher perceptions of physics' importance in engineering than students in the Chilean institution. Male and female students have similar perceptions about the relevance of physics. However, female students have a slightly higher perception of physics' importance for their ongoing studies in engineering than their male peers in the Mexican institution, opposite to what the results show in the Chilean institution. Reflecting upon the results and discussion of this contribution, some recommendations are: redesign physics courses to include activities in which students are in contact with real-life situations in classes, emphasizing the engineering part of the problem; promote active learning strategies in which students participate in the construction of their learning by interdisciplinary and gender-perspective approaches; and, include the student perspective in the curriculum and teaching materials by involving the higher-year students to demonstrate the relevance of physics to their first-year peers. As students are aware and perceive the relevance of their learning, they will be able to apply their knowledge in different academic careers and professional life situations.

Keywords: student perceptions; relevance of physics to engineering; gender influences on perceptions; educational innovation

- Weixia Gao, Wei Wang and Jihong Yu** 1186–1200 Insights into Sustainable Design Education: A Bibliometric and Visual Analysis

In recent years, research on sustainable design education (SDE) has attracted worldwide attention, but the current situation, theme and development trend of this field are still unclear. Based on the Web of Science Core Collection (WOSCC), this paper draws a knowledge map with 1265 papers published in Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI) and Science Citation Index Expanded (SCI-E) database as the source, and uses the visualization software Bibexcel and CiteSpace to systematically examine the knowledge output characteristics, cooperation networks, emerging hotspots, thematic context, knowledge base and frontiers of global SDE research from the perspective of bibliometrics. It is found that the number of SDE

publications is increasing rapidly, and the interdisciplinary nature is strong. The cooperation between authors and institutions is relatively weak, and cooperation among countries focuses on the USA, Japan, South Korea and member states of the European Union (EU). Hotspots form a four mainstream research themes distributing at content, relation, practice and object level. 22 papers play a key role in SDE field development. The frontiers are divided into three evolution stages: the concept-oriented from 2010 to 2014, the path-oriented from 2015 to 2017, and the organization-oriented stage from 2018 to 2020. The discussion of this study can provide reference for those interested in design education (DE), engineering education (EE) and other fields related to sustainable development (SD).

Keywords: bibliometric analysis; sustainable design education; Bibexcel; CiteSpace; knowledge graph

A. A. Del Savio, L. M. Cáceres and K. Galantini 1201–1214 A Methodology for Embedding Research Competencies in an Undergraduate Civil Engineering Program

Research and its relationship with undergraduate education plays a decisive role in the training of new engineering professionals with a greater affinity for basic and applied research as a fundamental tool in their professional performance and a pillar for lifelong learning (LL). The study aimed to improve the research competencies of civil engineering students from the *Universidad de Lima*. To achieve this goal, a methodology that allows the acquisition of them gradually, throughout the curriculum, has been developed. Didactic-methodological tools were introduced transversally using a gradual, incremental, and progressive process to promote and develop student research competencies. To follow up on how this process evolved, the acquisition status of research competencies among a group of students was monitored and followed up over four consecutive semesters for two years. The implementation mechanism was based on immersing the students in different types of research exercises depending on their semester by developing exploratory, descriptive, and experimental/predictive research activities. The results indicate that the proposed methodology, Gradual Implementation Research Competencies (GIRC) Program, improved students' acquisition level of research competencies. It was possible to standardize a methodology for the development, improvement and evaluation of students' research competencies, acquired through research exercises. The most representative products generated from the design and implementation of this methodology are: research competencies proposal, a rubric to assess them, and the Matrix of the Gradual Implementation Research Competencies Program with the proficiency levels expected for each curriculum year.

Keywords: undergraduate research; competencies; lifelong learning; innovation; civil engineering; rubric

Mary Luz Mouronte-López and Juana Savall Ceres 1215–1230 Analyzing Enrollment in Information & Communication Technology Programs and Use of Social Networks Based on Gender

This paper aims to analyze the gender dependence in the enrollment in the bachelor's or equivalent levels, with a strong focus on the Information and Communications Technology (ICT) field. The study is carried out with 12 nations included in the Organisation for Economic Co-operation and Development (OECD). The relationships with certain socio-economic factors (such as unemployment rate, government budget allocations for Research and Development (R&D), better life index, annual wages per full-time, score in the OECD's Programme for International Student Assessment (PISA report), educational attainment, student skills, Gender Inequality Index, etc.) and other indicators related to the use of ICT are studied. Information was retrieved from the Organization for Economic Co-Operation and Development (OECD) website and from the United Nations Development Program Human Development Reports, which was elaborated in the context of the United Nations Development Programme. A statistical analysis of the enrollment and its relationships with other socio-economic and ICT variables is carried out. In order to perform the analysis, various software programs, in R programming language, were implemented. Gender dependence on the use of the Twitter and Instagram networks is also examined, in order to check whether the interactions relating to particular topics present a similar pattern to those observed in the enrollment, per field of study. For the realization of this study, several software programs were developed in Python. The implementation of these programs followed a waterfall life cycle, including requirements definition, physical implementation and testing activities. Some of the conclusions point out that there is no relationship between the number of students enrolled in ICT programs and the average score obtained by the 15-year-old students in the PISA report 2018. This research shows that countries with strong investment in research and development (Ireland, Poland, New Zealand) have a higher number of women studying ICT programs. The frequency indicators related to the use of technological and digital resources (the use of Internet daily or almost every day (%), the use of a computer (%), downloading and installing of software from the Internet (%), the creation of a web page (%), the installation or replacement of an operating system (%)) do not show significant differences between the sexes. Twitter and Instagram show a significant gender dependence, according to the topic addressed, but the pattern observed is not the same as that detected in enrollment by field of study. Research findings can help to gain a deeper understanding of the situation of women's enrolment in ICT programs, while some suggestions can also be made for the development of educational and social policies, with the intention of increasing women's participation in these programs.

Keywords: ICT; gender; equity; inclusivity; comparative study; tertiary education; social networks; technological resources

Fermín Sánchez-Carracedo, Ferran Sabate and Karina Gibert 1231–1243 A Methodology to Assess the Sustainability Competencies in Engineering Undergraduate Programs

This paper presents a methodology to find out whether or not engineering students perceive sustainability learning throughout their studies at the university. The methodology is applied to students from Barcelona School of Informatics (FIB). The sustainability questionnaire of the EDINSOST project is used as a tool to determine student perception about their sustainability learning. The questionnaire contains 34 questions related to four sustainability competencies: (C1) Critical contextualization of knowledge establishing interrelations with social, economic and environmental, local and / or global problems, (C2) Sustainable use of resources and prevention of negative impacts on the natural and social environment, (C3) Participation in community processes that promote sustainability, and (C4) Application of ethical principles related to the values of sustainability in personal and professional behaviors. The questionnaire was submitted to the students of two first-year subjects and those who complete the Bachelor Thesis, with the aim of determining the initial level of sustainability that students have at the beginning of their studies with regard to that perceived when they graduate. The results show that students declare an improvement in the sustainability learning in the 34 questions analyzed, and that the competency of which they perceive to learn the most is "participation in community processes that promote sustainability". On the other hand, the competency in which they perceive themselves less prepared is the "application of ethical principles related to the values of sustainability in personal and professional behaviors".

Keywords: ESD competencies; competences' assessment; sustainability; education for sustainable development; student surveys; EDINSOST Project; sustainability map; data science

Laura A. Gelles and Susan M. Lord 1244–1260 Pedagogical Considerations and Challenges for Sociotechnical Integration within a Materials Science Class

This paper describes the creation and refinement of sociotechnical content within an introductory Materials Science and Engineering (MSE) course by incorporating principles of sustainability (i.e., social and environmental context), interdisciplinary collaborations, and best pedagogical practices. The paper uses student data from focus groups and interviews, final exam responses, and researcher and instructor reflections on the practical pedagogical realities of teaching sociotechnical modules. Our results show that students showed a greater awareness of social and environmental issues but also expressed a need to engage beyond a surface level of awareness so that they can see the direct impact of engineering decisions on people and the environment. Additionally, while many students expressed interest in incorporating social and environmental considerations into their engineering decisions, they also perceived that they would have limited power or agency to do so as newly hired engineers because they believe their employers only care about their economic bottom-line. Students struggled with seeing the value of sociotechnical content within an

engineering culture that prioritizes technical over other considerations. To effectively convey the value for this content, it is important for instructors to make pedagogical choices based on best practices including assessment and reinforcement and to reframe engineering culture to embrace ambiguity and acknowledge students' feelings of lack of agency and help them develop strategies for successful careers. Lastly, we present a preliminary framework for developing and implementing sociotechnical modules within undergraduate engineering courses for those who are interested in engaging in this type of work.

Keywords: undergraduate engineering; sociotechnical; sustainability; materials science; modules

Kyle M. Whitcomb, Alexandru Mariés 1261–1273 Examining Gender Differences in a Mechanical Engineering and Materials Science Curriculum
and **Chandralekha Singh**

Women are severely underrepresented in many engineering majors, e.g., Mechanical Engineering and Materials Science (MEMS). Here, we investigate gender differences in the predictive relationship between students' high school GPA and foundational mathematics, science, and engineering courses in the first two years of an undergraduate MEMS curriculum using ten years of institutional data. We use multi-group Structural Equation Modeling to analyze the strength of these predictive relationships and gender differences both in these relationships and in course grades. We find a strong predictive pathway from high school GPA to overall first-year performance to advanced mathematics courses and finally to second-year MEMS courses. Further, women's higher average high school GPA than men is consistent with higher grades in all first-year courses except physics. The underperformance of women majoring in MEMS in physics compared to what is predicted based upon their high school GPA may be a sign of inequitable and non-inclusive learning environment in physics courses and is consistent with the low self-efficacy of women in physics throughout their engineering major in our prior research. These findings can be useful in engaging physics departments to focus on equity and inclusion and devise strategies to improve the learning environment so that female engineering students do not underperform compared to what is predicted based upon their high school GPA.

Keywords: gender, equity; inclusion; structural equation modeling; engineering education

Liliana Fernández-Samacá, Oscar Iván Higuera-Martínez and Camilo Andrés Sanabria-Totaitive 1274–1288 Building Small Prototypes in a PBL Intervention for Learning Automatic Control Systems

This paper introduces a Project-Based Learning (PBL) intervention for the learning of automatic control systems. This intervention explores the building of local platforms for experimentation as a learning trigger; an educational experience that covers two issues: (i) to encourage students to develop both engineering skills and transversal skills in an exemplary learning scenario, trying to face several challenges of control education, and (ii) to make an affordable experimental set-up for laboratory practices. The proposed PBL intervention, defined into a curricular alignment model, appears as an integrating solution that involves teaching, learning and evaluation activities, learning outcomes, learning spaces and staff in the building of small control plant prototypes, whose elaboration must meet design requirements, recreating a professional task. The results obtained from the students' feedback and teachers' observations show advantages including the application of previous knowledge and concepts from other areas, especially signals and electronics, practical experimentation, strengthening transversal skills, working with others, and the design of a plant prototype from a constructionist view. Nevertheless, participants commented that their workload increased considerably, and the tutoring results in a more demanding environment than in teacher-centred models.

Keywords: project-based learning; control education; learning by doing; engineering education

Laura J. Leslie, Paul C. Gorman and Sarah Junaid 1289–1299 Conceive-Design-Implement-Operate (CDIO) as an Effective Learning Framework for Embedding Professional Skills

Engineering education requires the development of professional skills alongside technical expertise. Active, project – and problem-based learning have all been shown to be an effective method for learning and teaching and the CDIO (Conceive-Design-Implement-Operate) framework is internationally recognised for this. The aim of this study was to evaluate the effectiveness of our CDIO approach to undergraduate Mechanical Engineering degree programmes through analysis of student confidence in a variety of professional skills. Two questionnaires were given to students at the start (QNR1 n = 109) and end (QNR2 n = 117) of their final year of study in 2016/17, 2017/18, and 2018/19, including a list of key skills for students to rate their confidence levels. Results showed that students were highly confident in a number of professional skills including “problem solving” (4.20/5), “communication” (4.08/5) and “teamwork” (4.13/5), and that almost 90% of students used the CDIO process during their Final Year Project (FYP). Students recognised the importance of their academic advisors in the development and completion of their FYPs, particularly in areas such as defining the project aims (mean 85% agreement of importance), but also accepted that responsibility was predominantly their own or shared in all areas of the project. Only 5.4% and 11.1% of students thought it was the advisors responsibility alone to “Implement the Project” and “Define the Project Aims” respectively. This is a positive indication that CDIO is an effective methodology for giving students confidence in the professional independent and team working skills required post-University.

Keywords: engineering education; skills; CDIO; active learning; project-based learning; problem-based learning

Jelena Milošević 1300–1312 Implementing a Blended Design Studio Model in Architectural Engineering Education

This paper reports an exploratory case study on applying a blended learning environment in a studio course that introduces students to the challenges of designing spatial structures at the master studies of architectural engineering. In response to current technological advancements, changing generation, and demands of architectural practice, a model that blends conventional learning methods with online features was used to expand the design studio's activities and foster communication, collaboration, and connectivity. Furthermore, this approach promoted the implementation of the studio curriculum that interactively combines analytical and systematic procedures with explorative design exercises, seminars, workshops, literature studies and organized reflection, computer program demonstrations, physical model studies, generative design explorations, fabrication of small-scale prototypes, and design presentation. The effects of redesigned studio layout were evaluated based on data collected from the learning management system and the surveys conducted at the beginning and the end of the course. Obtained information and produced design artifacts demonstrate that blended studio assisted students in developing in-depth content knowledge, critical thinking, creativity, and skills by working in a stimulative, interactive and inclusive environment that better meets a new generation of design students' needs.

Keywords: architectural engineering education; e-learning, blended learning; computer-supported collaborative work; studio design curriculum

Kai Jun Chew 1313–1329 Interaction Between Learning Assessment and Student Motivation: A Scoping Review

Interaction between assessment and student motivation is a relatively understudied topic in engineering education. Though research and scholarship on both individual constructs are plenty and expansive, literature on the topic is not substantial relative to either of the individual concepts. It is essential to study such interactions as literature on assessments typically focuses on teaching improvement but is scarce from the student perspectives. On the other hand, motivation in engineering education usually focuses on improving content and pedagogies, but not assessment. Thus, this scoping review begins to address the research gap by providing an overview of the state of existing literature on the interaction in the undergraduate context. Grounded in scoping review methodologies, this review found that intentional study on the interaction is limited. Many of the articles scoped show motivation either hinted (no theoretical grounding) or emerged from the findings (no initial plan to include motivation in the

study). Besides, most articles employed quantitative methods. These findings warrant a systematic literature review to be conducted on the topic to portray and describe further the research gaps, which can subsequently promote efforts to address the gap in engineering education. Further, the review recommends the engineering education community use diverse motivation theories and research methods to study the topic.

Keywords: assessment; learning assessment; motivation; motivation theory; learner-centered pedagogy; scoping review

F. J. S. Velasco, José-Ángel Díaz-Madrid, 1330–1342 Students' Perceptions of Key Competencies Supporting Work-Integrated Learning
Inmaculada Arboleda-Guirao, Óscar de Francisco Ortiz, J. A. B Conesa, Nicolás Madrid García, Andrés Dolón Payán, Carmen de Nieves Nieto and Ricardo Teruel Sánchez

In this paper we explore the perception that industrial organization engineering students had after facing a compulsory, long-duration practicum oriented to develop key professional skills as management, analysis, diagnosis, resolution and organization of production and management and business administration in real professional environments. Specifically, we seek to explore the competencies and input provided to these students during their training stage as an Air Control and Defense Officer at the Spanish Air Force. In this case, the degree syllabus was designed so that the students could acquire the competencies related to industrial engineering, telecommunications, electronics or management linked to this profession. The study was based on the 141 students' feedback as well as the assessment by the professional mentors and the academic faculty. Results revealed that transversal competencies (also known as cross-curricular or soft competencies) are crucial. According to students' perceptions, competencies related to problem solving, team integration, communication and management play a major role for them to become successful in the practicum. In addition, 92% of these students held the view that the competencies acquired during the degree subjects helped them to finish the practicum satisfactorily. They valued the new knowledge and aptitudes they received during the process.

Keywords: practicum; perceptions; competencies; engineering students; industrial engineering; air force

Benjamin D. Chambers, Homero Murzi, 1343–1358 Course Development in a First Year Engineering Program: The Interplay of Autonomy, Peer Relationships, and Content
Matthew James, David Gray and Holly M. Matusovich

While much is known about the student experience in large first year engineering programs, little is known about the experiences of the faculty engaged in teaching and course development. To begin closing this gap, we conducted a collective autoethnography to understand the faculty experience in executing course development in a large first year engineering program. Grounded in Self-Determination Theory, we focused on faculty motivation and addressed the research question: How does the interplay between faculty autonomy, course content, and departmental collegiality affect the course development process in a large first year engineering program? Individually, the participants reflected on a series of questions and then we engaged in collective data analysis. Our results show that autonomy plays an important but complex role in course development. Faculty who engaged in course development work on behalf of a larger team of instructors identified faculty autonomy as an important outcome of the course development work, i.e., they wanted faculty members to have room to teach in their own individually meaningful ways. At the same time, course developers confirmed that specifying common course subject content was a necessity in a common first year engineering course taught by multiple instructors. They recognized that this specificity curbed individual autonomy, resulting in a need for course developers to balance autonomy while maintaining collegiality when making content choices. Achieving balance is particularly challenging when collegiality is a departmental value that is enacted though not always articulated. Our findings advance the current knowledge base on faculty experiences in first year engineering programs and offer a number of practical implications.

Keywords: faculty development; faculty motivation; autoethnography

Alicia Triviño-Cabrera, Antonio Jesus 1359–1370 Competition-based Learning in Engineering Degree Programs
Yuste-Delgado, Juan Carlos Cuevas-Martínez and Salvador Pineda

Competition-based learning is a technique in which students compete when performing an activity or a series of tasks with the objective of enhancing motivation, communication skills and creativity. This paper presents a literature review to determine whether competition-based learning improves students' engagement and motivation in the context of engineering studies related to the Information Technology. It also investigates parameters that make the approach successful for those studies.

Keywords: competition-based learning; competition; engineering; active learning; gamification; group; motivation; engagement

Ahmed Ashraf Butt, Kadir Kozan and 1371–1381 The Relationship between Students' Study Strategies and their Academic Performance in an Introductory Engineering Course with Standards-Based Grading
Muhsin Menekse

The current study explored the relationship between engineering students' study strategy use and their academic performance in an introductory engineering course. Mediation analyses informed by preceding correlational analyses were conducted on data emanating from 179 engineering students. The results revealed that problem set performance functions as a full mediator between study strategy use and final course scores, which held true for both study strategies and the most relevant five strategies. In other words, employing the relevant study strategies led to a similar relationship pattern, which did not change the nature of the relationship among study strategy use, problem set performance, and final course scores. Consequently, these findings indicate that the use of study strategies that specifically encourage self-regulated learning (e.g., reviewing past performance, seeking help) relates to a higher academic performance in an introductory engineering course with standards-based grading.

Keywords: academic performance; engineering education; first-year engineering; self-regulated learning; standards-based grading; study strategies

Karen E. Rambo-Hernandez, Rebecca 1382–1397 Valuing Diversity and Enacting Inclusion in Engineering (VDEIE): Validity Evidence for a New Scale
A. Atadero, Christina H. Paguyo, Melissa Morris, Seoyeon Park, A. M. Aramati Casper, Blaine Austin Pedersen, Jeremy Schwartz (Graduate Student) and Robin A. M. Hensel

The purpose of this paper is to detail the initial validation of a scale to assess engineering students' attitudes toward the value of diversity in engineering and their intentions to enact inclusive behaviors. In study 1, we administered the scale four times. We subjected the first administration to exploratory factor analysis (EFA), and the remaining three administrations to both confirmatory factor analysis (CFA) and tests of longitudinal measurement invariance (LMI). All tests indicated strong evidence for the internal structure of the factor structure of the survey. The four factors were: engineers should value diversity to (a) fulfill a greater purpose and (b) serve customers better; and engineers should (c) challenge discriminatory behavior and (d) promote a healthy work environment. In study 2, we again assessed the structure of the data as described in study 1 and then used the scale to assess potential differences between undergraduate students who participated in activities designed to promote diversity, equity, and inclusion (DEI) ($n = 116$) and those who did not ($n = 137$). Students in the intervention classes demonstrated a small statistically

significant increase in their intention to promote a healthy team environment in reference to the comparison classes. No differences were observed between the classes on the other factors. Future directions and implications are discussed.

Keywords: measurement; diversity; engineering students; survey; instrument development

Yuzhen Luo, Kurt Becker, John Gero, 1398–1413 Systems Thinking in Engineering Design: Differences in Expert vs. Novice
Idalis Villanueva Alarcon and Oenardi Lawanto

Systems thinking is a way of seeing and talking about the system so that we can understand and work with the system. It is both a cognitive ability and skill that is desired amongst engineers because of the complex problems that they are expected to solve in the workplace. Developing systems thinking capabilities of the engineering workforce is an industry endeavor as well as a desirable learning outcome for engineering education. This opens opportunities for research to better understand systems thinking of experts (professional engineers) in industry and novices (engineering students) in postsecondary education. The purpose of this study was to understand and compare the differences between expert and novice systems thinking in engineering design. Knowledge of experts and novices in their systems thinking can help inform engineering education on ways to bridge this gap in post-secondary settings. Using tools developed from Function-Behavior-Structure (FBS) Ontology, existing protocol data for 61 teams of 2 (18 professionals, 19 seniors, and 24 first-year students) underwent systems hierarchical coding and statistical analysis. Results show that systems thinking of professionals and senior engineering students are similar while first-year students were significantly different from their counterparts. This paper discusses several implications for systems thinking in engineering education and future research.

Keywords: systems thinking; expert-novice; problem decomposition and recomposition; engineering education

Uchenna Asogwa, T. Ryan Duckett, 1414–1428 Comparing Engineering Problem-Solving Ability and Problem Difficulty
Amanda P. Malefy, Lindsey Stevens, Between Textbook and Student-Written YouTube Problems
Gale Mentzer and Matthew W. Liberatore

Problem solving is a signature skill of engineers. Incorporating videos in engineering education has potential to stimulate multi-senses and further open new ways of learning and thinking. Here, problem solving was examined on problems written by previous students that applied course concepts by reverse engineering the actions in videos. Since the videos usually come from YouTube, the student-written problems are designated YouTube problems. This research focused on examining the rigor of YouTube problems as well as students' problem-solving skills when solving YouTube problems compared to Textbook problems. A quasi-experimental, treatment/control group design was employed, and data collected was evaluated using multiple instruments. NASA Task Load Index survey was used to collect ~1200 ratings that assessed rigor of homework problems. Problem-solving ability was assessed using a previously-developed rubric with over 2600 student solutions scored. In the treatment group where students were assigned ten Textbook and nine YouTube problems, students reported an overall similarity in rigor for both YouTube and Textbook problems. Students in the treatment group displayed ~6% better problem solving when completing YouTube problems compared to Textbook problems. Although higher perceptions of problem difficulty correlated with lower problem-solving ability across both groups and problem types, students in the treatment group exhibited smaller decreases in problem-solving ability as a result of increasing difficulty in the Textbook problems. Overall, student-written problems inspired by YouTube videos can easily be adapted as homework practice and possess potential benefits in enhancing students' learning experience.

Keywords: problem solving; visual communication; problem-based learning; student perception

Maurice Danaher, Anthony Rhodes and 1429–1440 Applying the Computing Professional Skills Assessment Method to ESL
Ashley Ater Kranov Students in a Computing Program

Professional skills, also known as non-technical, transferable or 21st century skills are recognized worldwide as very important for university graduates. These skills include communication, problem-solving and the ability to function successfully on a multi-disciplinary team. While academic programs worldwide strive to develop a solid professional skills base in students, these skills are notoriously challenging to teach and assess. This paper presents the Computing Professional Skills Assessment (CPSA), a performance assessment of the professional skills learning outcomes identified by the Accreditation Board for Engineering and Technology (ABET), for the computing discipline. The assessment consists of a performance task, a rubric and an implementation method. The CPSA has been developed in an iterative manner and results suggest that it can accurately and consistently elicit and measure the targeted professional skills in computing students within appropriate contexts. Considering two components of the Communities of Inquiry model, cognitive and social presence, specific reliability and validity protocols were developed for the CPSA. These involved a pilot study, iterative development and assessment of the rubric, establishment of interrater reliability, the production of computing specific scenarios which are suitable for non-native English language speakers, and an implementation strategy using asynchronous discussion boards. Based on our findings through more than 50 CPSA implementations over a seven-year period, we have found that the instrument can be used reliably and validly as a measure of the professional skills learning outcomes for English as a second language learners in a computing program.

Keywords: asynchronous discussion board; learning outcomes; professional skills; rubric

Bahar Memarian and Susan McCahan 1441–1453 Constructive Alignment Integrated Rating (CAIR) in the Assessment of
Engineering Problem-Solving

There is a need to characterize engineering problem-solving errors on student solutions to provide more formative information in a manner that aligns with the course and program learning outcomes. In this study a new formative feedback framework schema, designed to improve the apparency in feedback delivery, is proposed and tested. The design of the schema is inspired by the concept of work domain analysis from industrial engineering. Unlike conventional marking which uses point deductions to imply error severity, the new instrument is centered on feedback that characterizes the nature of each error. The schema was tested with teaching assistants (assessors) in a three-part semi-randomized evaluation trial. A group of engineering assessors ($n = 33$) evaluated problem solutions using the new schema and conventional grading. The new system significantly enhanced the proportion of descriptive feedback assessors provided across solutions ($p < 0.001$, effect size = 0.46). The new system also significantly decreased the speed of feedback delivery as compared to conventional grading ($p < 0.001$, effect size = 0.60). Conventional grading, however, scored significantly higher on the SUS usability score ($p < 0.001$, effect size = 0.73). Within the scope of the electrical engineering problem solutions tested, the new schema significantly improved the quality of formative assessment assessors provided relative to conventional marking. However, the usability of the instrument still needs improvements. Future work could include creating a digital interface based on the proposed framework to improve the evaluation experience for the assessors.

Keywords: constructive alignment; formative feedback; assessment; problem-solving; work domain analysis

Rebecca Komarek, Angela R. Bielefeldt 1454–1465 Influences of Engineering Students' College Experiences on Leadership Skill
and **Daniel W. Knight** Assurance

With a growing interest in developing leadership skills among engineering students comes the need to better understand students' experiences that contribute to leadership abilities. The purpose of this study is to explore the engagement of undergraduate engineering students and learn how it relates to their leadership skill assurance (LSA), the belief in their ability to exhibit leadership skills in their career or studies after graduation. The connection of engagement to leadership development is taken within the context of the College Impact Model. A case study quantitative method was used to gather data from 1,770 graduating engineering

students from a large, public university. The study uses generalized linear modeling (GLM) to measure LSA, based on student *classroom*, *out-of-class*, and *curricular* experiences, as outlined by the College Impact Model. Results showed that activities from each category were significant in their relationship to LSA. The highest rated factors were involvement in Space Grant (an out-of-class activity), quality of peer interactions (a classroom activity), and choosing an engineering management minor (a curricular decision). Identification of activities and level of satisfaction that align with higher LSA help engineering educators to determine where to contribute resources toward the development of leadership in engineering students.

Keywords: leadership; co-curricular; extracurricular; involvement; engagement