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Ahmad Ibrahim

505 Editorial

Mary Pilotte, Matthew W. Ohland,
Susan M. Lord, Richard A. Layton
and Marisa K. Orr

506–518 Student Demographics, Pathways, and Outcomes in Industrial Engineering

Industrial Engineering (IE) is known for its high participation of women and welcoming culture. This multi-institution longitudinal study of student demographics and educational outcomes in IE affords more detailed insights into disciplinary dynamics by describing the demographics, trajectories, and outcomes of IE students into, out of, and through nine IE programs. This research presents a quantitative perspective of IE student pathways and outcomes disaggregated by race/ethnicity and gender. The study includes 10,994 IE first-time-in-college and transfer students in the USA. Framed using Astin's college impact model, student pathways vary by gender and race/ethnicity and are both an outcome of the environment and an important factor influencing the environment. The outcomes for all populations in IE are notably positive compared to other disciplines. Hispanic and Black engineering students chose IE at higher rates than Asian and White students, resulting in more racial/ethnic diversity than the engineering aggregate. Within each race/ethnicity, women in engineering chose IE at higher rates than men. Hispanic men and women achieved the highest graduation rates. Black, White, and Hispanic women in IE all graduated at higher rates than their male counterparts. More students of all groups except Black men switched or transferred into IE than left. This study complements prior qualitative work leading to a deeper understanding of IE, which is noted as attracting and retaining a diverse student population. Detailed descriptions of IE student pathways and educational outcomes can also guide other disciplines that seek to improve diversity and student success.

Keywords: industrial engineering; retention; choice; race/ethnicity; gender

D. Jake Follmer, Sarah E. Zappe,
Enrique D. Gomez, Esther W. Gomez
and Shane E. Haydt519–526 Changing the Conversation: Impact of a Seminar-Based Classroom
Innovation on Student Perceptions of Engineering

Examination of student perceptions of engineering has the potential to elucidate factors that affect enrollment and retention in engineering fields. The main goal of this study was to examine the effect of a classroom intervention—an engineering student ambassador program (Engineering Ambassadors)—on first-year engineering students' perceptions of engineering and engineering self-efficacy. Student changes in perceptions of engineering were examined in two studies. Results from Study 1 indicated evidence of the benefit of the engineering ambassador innovation on students' perceptions of engineering as well as positive ratings of the ambassador visits. Study 2 corroborated the findings of positive ratings and perceived benefits of the engineering ambassador visits, and demonstrated increases in engineering self-efficacy among students receiving the engineering ambassador intervention compared with students who did not receive the engineering ambassador intervention. Implications for increasing student interest in engineering based on the implementation of the classroom innovation are discussed.

Keywords: attrition; retention; women; underrepresented students; Engineering Ambassadors; engineering self-efficacy

Aileen Huang-Saad and Sergio Celis

527–537 How Student Characteristics Shape Engineering Pathways to
Entrepreneurship Education

As higher education works to meet the challenges of the changing economy, engineering programs have significantly increased their programs in entrepreneurship as a mechanism for fostering 21st century skills in a diverse workforce. In an effort to balance the rigorous academic technical requirements of an engineering degree, entrepreneurship programs leverage both curricular and co-curricular programming, offering students different paths to entrepreneurship development. However, little is known about the distribution of these opportunities amongst different groups of students. The purpose of this investigation is to examine whether the pathways to entrepreneurship education are influenced by student characteristics. Institution and participation data of 1,018 undergraduate students were collected from an entrepreneurship program anchored in a large, Midwest, public research university, college of engineering, center for entrepreneurship. Logistic regressions were used to examine the differences and similarities between students enrolling an entrepreneurship curricular program and their participation in co-curricular activities. Our data indicates that gender, nationality, and grade point average (GPA) are key factors in determining the type of entrepreneurship participation students choose to pursue in the university environment. We also found evidence of the curricular program acting as a gateway to engagement with entrepreneurship beyond the classroom. These data suggest that entrepreneurship programs should be cognizant of the influencers as well as the student pathways when developing programs to attract a diverse student base.

Keywords: engineering entrepreneurship education; co-curricular activities

Kayoko Nohara, Michael Norton and
Eriko Kawano538–547 Imparting Soft Skills and Creativity in University Engineering Education
through a Concept Designing Short Course

Universities need to add a range of soft skills to the range of technical specialities provided in engineering education to respond to demands for engineers who can solve complex problems in an international working environment, and which recognises social and

environmental issues (and associated stakeholders). Soft skills related to creativity, communication and teamwork abilities are often mentioned. But in addition, engineers planning to work for a company competing in the global market need to be aware of the increasing competition on non-performance factors incorporating artistic and aesthetic considerations into the design process. This paper describes a novel approach being used at Tokyo Institute of Technology by partnering with Musashino Art University to develop a 'concept designing' course where engineering and arts students work together in a short intensive course to develop a design based on an initial abstract concept. The 5 years of experience on this course allow us to assess the range of skills and experience provided against the initial objectives and student outcomes of the course. We conclude in this paper that such cooperation between engineering and arts has significant benefits for the creative process and in developing students' soft skills.

Keywords: engineering education; soft skills; creativity; communication; design

Ha Congying, Yan Zhaowen, Zhang Youguang and Su Donglin 548-557 The Open Experiment: An Experimental Graduate Course in Electronics Communications Engineering

This paper mainly discussed the novel open experiment graduate course in electronic information and engineering. The course is designed to teach postgraduates how to design, test, and simulate some basic experiments related to wireless communication systems and microwave transmission systems using modern instruments and computer-aided design (CAD) software. One of the objectives of the course is to assist postgraduates to understand the theoretical concepts of wireless systems, parallel DSP, embedded systems, electromagnetic waves, electromagnetic compatibility and optical communication systems through hands-on experiments and to make them more confident both in system design and analysis. The course also aims at increasing the interest of postgraduates in engineering and technology. Therefore, laboratory experiments that are complementary to the materials discussed in the theoretical part of the course are designed specifically to incorporate the use of several common instruments that students probably use extensively in their research fields. Complementing and expanding upon the materials covered in six basic courses is another merit of this laboratory-based course. Meeting the course requirements also helps students improve their oral presentation and report preparation abilities. The laboratory has provided more than 2000 postgraduates during the past ten years with the opportunity to acquire both in-depth theoretical understanding and hands-on experience in this rapidly growing discipline. The evaluation of the course indicates that most of the objectives are achieved.

Keywords: laboratory courses; open experiment; innovation

Geoffrey L Herman, David E. Goldberg, Kyle F. Trenshaw, Mark Somerville and Jonathan Stolk 558-574 The Intrinsic-Motivation Course Design Method

Because engineering faculty seldom use research-based instructional strategies, the engineering education community has become increasingly concerned with how to help faculty sustainably integrate education research into their teaching practices. We developed the Intrinsic-Motivation (IM) Course Design Method to make motivation theory accessible to faculty and to help faculty think more concretely about the costs that demotivate them and make their course designs untenable. Our course design method complements existing course design methods by providing an approach to designing for motivational outcomes. In this paper, we describe the IM Course Design Method and then illustrate how this method was used to refine the design of a sophomore-level engineering course that enrolled over 200 students. We then present evaluation evidence from this course to suggest that application of the method can increase students' intrinsic motivation in engineering courses.

Keywords: intrinsic motivation; course design; diffusion of innovation

Kazumasa Ohkuma, Masahiro Osogami, Naoki Shiori and Kazutomi Sugihara 575-587 Motivation Effects of Using Actual Robots Controlled by the Scratch Programming Language in Introductory Programming Courses

This paper reports on the effects of a teaching tool that controls actual robots during introductory education in computer programming among high school students. The effects of the tool were investigated by means of a questionnaire following two types of experience based programming classes, namely one class that used actual robots and one that did not. Questionnaire surveys were completed before and after the classes in order to determine whether or not the participants' level of interest in information and communication technology had changed. Statistical analysis of the questionnaire results showed that the use of actual robots is an effective way to raise students' level of interest in information and communication technology. It was found to be particularly effective among participants who liked subjects other than science and those who had a lower level of understanding information sciences that they were taught in high school.

Keywords: programing education; scratch; actual robot

Aharon Gero and Shai Mano-Israeli 588-595 Analysis of the Factors Motivating Students at a Two-Year Technological College to Study Electronics

Two-year technological colleges provide practical engineering training, allowing their graduates to become directly integrated into the employment market. Similarly to students at community colleges, students at technological colleges are usually from the socio-economic periphery or students with relatively low academic achievements. Using quantitative and qualitative instruments, the study described in this paper characterized the factors motivating students to study electronics at a leading two-year college in Israel. Fifty second-year electronics students took part in the study. According to the findings, the students are primarily motivated by interest in the studies (intrinsic motivation) and by recognizing their inherent value (identified regulation). However, an additional factor that should be taken into account is external regulation, according to which, some of the students are studying electronics at the two-year college for lack of any other option. The external regulation's relatively high weight could possibly be explained by the findings, according to which, the need for competence and the need for relatedness are only partially met in those students during their studies.

Keywords: electrical engineering education; two-year colleges; motivation

Qaiser Malik, James C. Witte, Naveed Zafar and Zamir Hussain 596-609 Influences on Freshman Attitudes toward Engineering: Lessons from a Case Study of a Major Engineering University in Pakistan

This 'evidence based practice paper' reports influences on freshman attitudes toward engineering at a major engineering university (MEU) in Pakistan. The assessment is based on surveys conducted with incoming MEU students before and after their participation in a one-credit engineering education foundation course (EGR 100). This course is designed to make students passionate about engineering, enable them to become active learners, and prepare them to undertake the rigors of an engineering curriculum. Attitude data was collected at the beginning and toward the end of the course, using a modified version of the Pittsburgh Freshman Engineering Attitudes Survey (PFEAS). Additional items recorded student demographics. Analyses in the paper include pre and post course comparisons of 718 students who completed both the pre and post course surveys. The paper also considers the impact of gender and type of secondary education. The paper concludes with a discussion of the implications of our findings for engineering education at MEU and other engineering programs.

Keywords: engineering attitudes; freshman engineering; active learner; PFEAS

This article aims to describe two different project-based learning (PBL) experiences using NGO (Non-Governmental Organization) projects, and complemented with a volunteer program abroad (in Honduras and Kenya). The integration of the projects within the framework of the courses was promoted within a context of a project-based engineering school. The NGOs requested technical support in some projects, which students developed in their classrooms to offer real solutions. Throughout the summer, some student and professor volunteers traveled there to evaluate the situation, implement the projects and collect the data needed to move forth and determine new needs for the next academic year. The awareness brought about, thanks to working with the NGOs in the communities where projects were implemented, increased students' interest and involvement. Working with real projects, enhanced their motivation showing a positive impact on students' learning. This approach has contributed to their development in ethical values and sustainability awareness within a framework of Engineering Education for Sustainable Development. With these projects, students develop key skills as engineers, and as active global citizens, conscious and committed to addressing and solving sustainability problems in the real world.

Keywords: project-based learning; social responsibility; cooperation projects; volunteer programs; engineering education; sustainability

With a reduction of energy budgets and increasing aggregation of different applications, reconfigurable computing system is becoming a promising platform for future system-on-a-chip (SoC) designs. This paper presents a project-based course on reconfigurable computing systems. With the aid of an education platform, students learn to design their own mixed-grained reconfigurable architectures and implement a cryptographic algorithm. Combining both fine-grained Field-Programmable Gate Array (FPGA) and coarse-grained reconfigurable architectures (CGRAs), the course provides students an integrated view of reconfigurable computing system following the up-to-date scientific development in this area. Also, students gain practical hands-on experience of designing reconfigurable computing system using hardware-software co-design methodology. More than fifty students participate a comprehensive survey after the course and twelve faculty members of the similar research interests also appraise the course. Both the survey feedback and the course assessment confirms that the objectives of the course are well achieved.

Keywords: reconfigurable computing; engineering teaching; hardware-software co-design; project-based learning

In this paper, we propose a project-based framework to help teaching and assessment of Architectural design modules in an informative and fair way. The framework is based upon criteria-based assessment and uses rubrics to guide the assessment process. Using this framework, the students can fully understand the evaluation criteria by practicing peer-to-peer evaluation, and instructors can have useful feedback about weaknesses of their students and/or their teaching methodologies. By mapping students' results into required students' skills, monitoring of students over several levels of study becomes possible; this supports efficient progressive learning. The proposed approach has been evaluated by using it to assess A group of thirty students in design-I module; then their results were compared to another group of thirty assessed heuristically without it. The initial evaluation of the approach shows its effectiveness.

Keywords: architecture design; assessment; criteria-based; rubrics; peer-to-peer evaluation; progressive learning

A critical part of students' development and persistence as engineers is their acquisition of a professional identity. Prior research indicates that science, technology, engineering, and math (STEM) students tend to over calibrate their level of professional identity. This suggests that their self-determined level of professional identities are likely inflated when compared to the levels of identity that their communication would indicate—which may appreciably influence their professional engagement and tenacity as an engineer as well as their perceptions of engineering as a profession. One area that has not been explored is the underlying factors that influence these self-elevated perspectives by the students. The study explores the individual, social, and systemic domains as well as historical foci of 275 undergraduate engineering students' perceptions of the engineering profession. Findings indicate that students' self-proclaimed levels of professional identity are higher than the development levels they convey in their survey responses. We found that their perceptions tended to be aligned with their individual view of engineering, which were guided by the historical notion that an engineer is a *Mediator* of science, math, and technology, a perspective that is not aligned to current definitions of 21st century engineering. Our exploratory study supports the importance of helping engineering students develop professional identities by attending to their understanding of the work, norms, and expectations of professional engineers and the role of a 21st century engineering professional.

Keywords: professional identity; engineering education; history; undergraduate; engineering student perceptions

Industry and accreditation bodies around the world require graduates to be able to demonstrate specific graduate attributes. Universities in this 21st century have responded to that call by embedding graduate attributes into their curricula. However, how can individual academics ensure that they are incorporating and assessing graduate attributes in their respective modules, which form part of the overall curriculum? This research question necessitates reflection as many academics are struggling to come to terms with what many of these graduate attributes really mean or entail. Moreover, a dearth of research publications exists on trying to define and explain these graduate attributes. The purpose of this article is to determine to what extent have the 10 graduate attributes, adopted by the Central University of Technology been embedded into the curriculum of the National Diploma in Electrical Engineering. A qualitative case study was used and data was collected using documentary review. All 36 study guides of the Electrical Engineering qualification were analysed. Results of this study show that 9 out of 10 graduate attributes are spread across the entire curriculum. The four most dominate graduate attributes were found to be Innovation and Problem Solving; Technical and Conceptual Competence; Numeracy, and Technological Literacy. Certain graduate attributes are clearly discerned in the learning outcomes while others are hidden in different teaching and learning activities. A key recommendation of this study is for academics to structure their learning outcomes in a way that addresses the incorporation and assessment of key graduate attributes required.

Keywords: graduate attributes; indicators; engineering; outcomes

This paper presents an example of engineering educational research as a means of improving the effectiveness of teaching through the identification of student challenges and the subsequent creation of educational strategies to mediate gaps and enhance student mastery of an engineering topic. Its specific focus is student assessment error analysis, an under-researched field in engineering education. The context of the study was a cohort of 133 students taking a reactor design module in a chemical engineering degree

programme. The study demonstrates how insights gained from a stringent data analysis of student test errors combined with teaching reflections can inform pedagogical redesign of a course. It discusses the utility of the research methodology used and how it can be deployed as a strategy in research-led engineering education.

Keywords: engineering education; student-centred education; evidence-based education; reactor design; student errors; student assessment error analysis

Reuven Katz and Iris Talmi

672–679 Teaching Industrial Design in Mechanical Engineering: A Laboratory for Design and Engineering

The introduction of novel information technologies has changed the product development process in industry. There is an ongoing integration between mechanical and industrial design, with both fields using somewhat similar design tools. Unfortunately, a large gap still exists between these two professions in academia. Mechanical design and industrial design are typically taught in different schools, using different educational methods, and emphasizing different topics in their curricula. Integration of these two academic disciplines in an academic course is rarely encountered. In order to overcome this limitation, we introduced a new laboratory course for design and engineering where we teach engineering undergraduate students, in addition to mechanical engineering practice, basic concepts of industrial design and allow them to gain hands-on experience. Each semester 16 undergraduate ME students participate in the laboratory. A survey conducted among students who completed the laboratory studies yielded very positive feedback: the majority of students responded that they appreciate learning and implementing the concepts of industrial design and integrating engineering practice with creative design.

Keywords: mechanical design; industrial design; product design; design education

Jesús Mataix, Carlos León and Juan F. Reinoso

680–692 Factors Influencing Spatial Skills Development of Engineering Students

Spatial skills are fundamental not only for engineers and architects but also for professionals in a great variety of fields. These skills are crucial also in the academic training of students of all ages. In the academic year 2012–2013, a large-scale study was made at the University of Granada (Spain) to evaluate the influence exerted on these skills by several factors related to personal aspects, experience, hobbies, and abilities. At the beginning of the term, a spatial test and a questionnaire were administered to 750 students in three majors (Bachelor's degrees in Civil Engineering, Chemical Engineering, and Industrial Electronic Engineering) who were studying courses on Graphic Expression. During the semester, the students were invited to participate in a set of voluntary spatial skills training activities based on exercises of freehand sketching. At the end of the term they were administered a spatial test again. General intelligence, problem-solving ability, gender, construction games, and experience in technical drawing are the factors more directly related to spatial skills. Furthermore, the training activities have shown a high degree of effectiveness in improving the students' spatial skills.

Keywords: spatial skills; spatial visualization; factors influencing; academic training; curricula

Tom Wanyama

693–702 Using Industry 4.0 Technologies to Support Teaching and Learning

It is a known fact that students learn more effectively when theory is supplemented by a large component of laboratories. But laboratory based learning is most effective when students are able to practice laboratories multiple times to review their work, reflect on it, test different scenarios, and discuss the results with their peers and instructors. In the School of Engineering Practice and Technology (SEPT) at McMaster University we have achieved this by providing remote laboratories using Industry 4.0 technologies. These technologies have enabled us to build industrial networks laboratories that are accessible onsite, and remotely online through the Internet. We call them McMaster Internet Laboratories or MiLabs in short (pronounced as My Labs). This paper describes how Industry 4.0 technologies are used to enable remote access to MiLabs; and how we have designed our laboratory sessions and laboratories based projects to maximize learning. Furthermore, the paper presents general analysis of students' performance and feedback which show that MiLabs is an effective laboratory platform.

Keywords: Industry 4.0; teaching and learning; industrial networks; internet laboratories; internet of things

Janko D. Jovanovic

703–711 Personalized Approach for Mobile Learning of Engineering Graphics

This paper presents the development, implementation and evaluation of an online tool for personalized mobile learning of engineering graphics. The online tool is designed to support the widespread mobile operating systems, such as Android, iOS, Windows 10 Mobile, as well as to be interactive and to enable "learning by doing". The framework for the developed tool includes Dropbox, as the file storage application, and AutoCAD 360, as an interactive CAD application with various tools for drawing. The study was conducted on a sample of 30 undergraduate students. The students were divided into the experimental group, using the developed online tool for personalized mobile learning, and the control group, using traditional learning tools. A statistical analysis of both samples was carried out in order to study the effectiveness of this online tool in the learning process. The results of the final test showed that the students from the experimental group were more successful than the students from the control group. Therefore, the use of the developed online tool for personalized mobile learning of engineering graphics can be considered an improvement in the teaching of engineering graphics.

Keywords: mobile learning; personalized learning material; engineering graphics

Óscar López-Zaldívar, Amparo Verdú-Vázquez, Tomás Gil-López and Rafael V. Lozano-Díez

712–722 The Implementation of Building Information Modeling Technology in University Teaching: The Case of the Polytechnic University of Madrid

The purpose of this research is to analyze the degree of competence in using and understanding Building Information Modeling (BIM), of construction undergraduates at the Polytechnic University of Madrid, from the beginning of their degrees until they get their first jobs. In order to achieve this, a survey was carried out of students from the four Construction Engineering year groups. The analyzed sample comprised 336 students (approximately 25% of all those registered). The results obtained indicate that the level of knowledge about BIM is less than 43% whilst 18% claim that they do not know what it is for. Despite the low percentage of knowledge, there is a high level of motivation, given that more than 98% of those surveyed express an interest in learning how to use it. Meanwhile, the absence of regulations, the lack of development of standard protocols of action and the perceived lack of profitability from using the tool during the period of education contribute towards students putting off learning it.

Keywords: building information modeling; BIM implementation; BIM teaching; curriculum development; construction education

Negar Beheshti Pour, David B. Thiessen, Robert F. Richards and Bernard J. Van Wie

723–740 Ultra Low-Cost Vacuum Formed Shell and Tube Heat Exchanger Learning Module

Hands-on experimentation with engineering equipment is one form of active learning which is often not experienced until a senior lab course. A major hindrance to this kind of experiential learning is the cost of equipment. Our group has developed a manufacturing method to bridge the price barrier by employing 3D printing and vacuum forming. In this paper, methods are described for the development and testing of a new low-cost (overall \$115), miniaturized, lightweight, see-through, easy and safe to use shell and tube heat exchanger (STHX) learning module, and corresponding results for engineering classroom implementations are highlighted. The implementation was done in one section of a two-section sophomore level material and energy balance course with 31 students and pre- and post assessment were compared to the other section with 43 students which had a standard lecture. Statistical analysis results show significant improvements for the intervention group, and no significant improvements on any questions for the control group. We think that the STHX can help students understand the practical definition of the system and

system boundary and conservation of energy as long as they experience a physical system that represents the energy conservation concepts in action. Student results and feedback presented in this paper provide evidence that students can take reasonable data with this low-cost apparatus in a 50-minute class period and they will have a positive attitude toward the STHX module that will provide further motivation to learn.

Keywords: active learning; hands-on learning; collaborative learning; thermal/fluids processes; low-cost desktop learning module; transparent miniaturized shell and tube heat exchanger; vacuum forming and 3D printing; energy conservation; system boundary

Irene O. Saracho-Pantoja, José R. Montejo-Garai, Jesús M. Rebollar and Jorge A. Ruiz-Cruz 741–750 Low-Cost Additive Manufacturing: A New Approach to Microwave Waveguide Engineering Education through 3D Printing

This paper explains the applications of additive manufacturing to microwave waveguide engineering education, in particular the advantages of the low-cost technique called Fused Filament Fabrication. The promptness to print models, the variety of feasible geometries previously unachievable by subtractive methods and specially the reduced price, make manufacturing designs available to students and small labs without great resources. In addition, it gives students the opportunity to be involved in a full design process, including the manufacturing and measurement of their own devices, with the invaluable experience which it entails. In order to illustrate the process, several well-known passive waveguide devices working in Ku band have been printed, metallized and measured: a band-pass filter, a diplexer, a branch-line coupler and a horn antenna. Finally, the analysis of results proves the potential of 3D printing, although the main limitations are also highlighted to give a deep insight of this new technology.

Keywords: additive manufacturing; coupler; diplexer; filter; horn antenna; Ku band; microwave education; waveguide; 3D printing

Kajan Srirangan, Lamees K. Akawi, C. Perry Chou, Marc G. Aucoin, Lyndia E. Stacey and Cheryl Newton 751–760 Use of a Case on Metabolically Engineered *Escherichia coli* to Develop a Framework for the Design and Analysis of Bioprocesses

Thematic case-based studies can be used by instructors to enhance critical thinking and knowledge in a holistic fashion, as well as improve students' cognitive and metacognitive processes. While case-based learning approaches have been long used in the teaching of business, law and medicine, they have yet to see widespread use in many engineering disciplines. Furthermore, empirical research on the effectiveness of case-based learning within engineering is still in its infancy. Herein, we describe the use and impact of case-based instruction implemented in a third-year undergraduate bioprocess engineering course at the University of Waterloo. The overall objective of our study was to link key concepts related to bioprocess engineering to "real-world" bioprocesses through a series of tutorial modules and research projects tied together by a common thematic case. The developed case focuses on genetically engineered *Escherichia coli* for the production of biofuels, specifically 1-propanol. The intent was to provide the students (n = 94) with the opportunity to gain a deeper understanding of biological systems by linking traditional fields of bioprocessing to an emerging field such as synthetic biology while also immersing students into situations that they could encounter while working in industry. Our results suggest that a majority of the students felt that the case was engaging and that the small-group based problem-solving exercises helped their understanding of design principles relevant to bioprocess engineering.

Keywords: chemical engineering education; case studies; thematic cases; conceptualized approaches; chemical engineering; bioprocess education; metabolic engineering education; synthetic biology