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Section I
Special Issue
Artificial Intelligence-Aided Engineering Education

Guest Editors
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Artificial intelligence (AI) is already starting to transform the way engineering systems are conceived, designed and managed, helping to maximize the chances of successfully achieving their goals. Engineering science, technology and research clearly benefit from AI and engineering educators should be able to make students aware of its potentials, teach them the necessary fundamentals of this field of study and guide them through the application of these algorithms and technologies to the development of real engineering projects, as necessary aspects in modern engineering programmes of study. However, the more relevant impact of artificial intelligence in engineering education goes beyond the application of a set of novel resources to solving specific engineering problems: In fact, the concept of "artificial intelligence-aided engineering education" refers to utilizing artificial intelligence techniques and resources for improving the teaching-learning process in higher education, especially in connection with scientific-technological studies. In this study, we concentrate on how AI techniques can support the teaching-learning process in engineering and we describe how AI can be swiftly introduced into any engineering programme. We also analyze the potential impact of AI on improving the overall operation of universities, as extremely complex systems managing myriads of data and countless processes and interactions.

Keywords: artificial intelligence; engineering education; project-based learning; service learning; optimization of resources; ethical issues

The proposed research describes the application of artificial neural networks in order to support curriculum planning and advance educational process at the level of higher education. The developed artificial neural network model contains three layers: input, hidden and output. The input layer includes parameters such as previous education, number of points that future student brings from high school, city in which the student finished high school and subject that the student chose for entrance exam. The predicted parameter is the number of students with specific previous education. The results could have a significant effect on curriculum planning thus supporting educational process. Teachers could adapt their courses according to the previous education of students and their knowledge. The evaluation of neural network with Root mean square error (RMSE) gave the value of 0.12 which is acceptable for predicting model. A Web based application is developed in order to enable teachers to obtain the results from the artificial neural network without specific knowledge about the methodology of neural networks. The created application was evaluated through one use case and validated with real data from last year.

Keywords: information technology; artificial neural network; web based application; curricula planning

Aiming at solving the current pain points of artificial intelligence (AI) education, a new AI course at W Booth School of Engineering Practice and Technology, McMaster University, was designed and delivered based on a paradigm called Project and Practice Centered Learning (PPCL). The overall teaching philosophy behind PPCL is: students should be systematically trained as future full stack artificial intelligence engineers who are capable to understand and implement feasible AI methods to solve real-world problems by building up systems which function completely to address practical issues in industry, business and daily life. Based on more interactive and practical training in hands-on activities, mini-projects, mid-term project, workshop, and capstone-like course final project, students learn to: (a) how to integrate AI sub topics to address issues raised from real-life, (b) how to create and analysis their own training and testing datasets, and (c) how to compare performance of different AI models, (d) inspire students' innovation ability, (e) cultivate their comprehensive ability to design and implement a sophisticated system individually, etc. Based on feedbacks from students and peers, the proposed PPCL based AI teaching and learning was effective. This pedagogy can also be applied to AI related courses and other technical engineering courses.

Keywords: project and practice centered learning; voice recognition; teaching strategy; AI education

This work presents an active learning methodology called Project-based learning (PBL) for developing artificial intelligence (AI) in a computer vision course of an undergraduate engineering degree. The objective of the course was to develop image recognition capabilities using Deep Learning (DL)/Machine Learning (ML) technics in real-world problems. The PBL learning methodology helped students search for real-world problems, develop complex solutions, and generate synergy among team members. The main role of the professor was to advise, guide and motivate the students throughout the course. The pedagogic innovation with active learning methodologies offered the professor the opportunity to create a dynamic motivating learning environment based on experiences. Each undergraduate engineering student had the opportunity to develop the skills and techniques of their profession: teamwork, proactivity, innovation, and leadership. The results obtained by the student teams showed problem-solving, including the use of automatic navigation equipment with AI, detection of the malaria parasite, recognition of non-human individuals to control vehicular traffic.

Keywords: artificial intelligence; artificial neural network; image recognition; machine vision; project engineering

Artificial Intelligence is the domain of computer science which includes the solving of problems in reasoning, knowledge representation, prediction, learning and perception areas. The large volume of data can be used for social media, e-learning, distance learning and e-commerce environment. Our research work includes the classification and prediction of students' performance in educational sciences. The analyzed results are forecasting the future plan in higher studies. In this work, we use TensorFlow Artificial Intelligence engine for classification. Deep learning is used for measuring academic performance in core courses such as mathematics, physics, chemistry, biology and computer Science. The performance can be measured in nonacademic activities also such as sports, yoga, art and social services. These papers gives prediction result using machine learning tools and give more comprehensive study of both academic and nonacademic activities. Here we take number of intermediate nodes from students' performance and number of deep learning objects from students' activities. The result is generated and compared using TensorFlow. The input of two thousand five hundred students' data is taken from Tamil Nadu Nagapattinam and Thirvarur Districts from education science department, 65% of data is trained data and 35% of data are test data. The accuracy factor is 75% to 85%. The prediction factor accuracy can be determined by using optimal configuration of TensorFlow engine. This result can be used for the benefit of the students to select their future studies and career development of students based on their higher secondary academic and nonacademic performance factors.

Keywords: artificial intelligence; deep learning; convolution artificial neural networks; TensorFlow; prediction

Section II
Contributions in: Multidisciplinary Projects, Biomechanics, Collaborative Learning, Virtual Prototyping, Industry 4.0, Engineering 5.0, Group Dynamics, Assessment, Additive Manufacturing, Ideation, Supply Chain, Building Information Modeling, Sustainability, Transportation, Teamwork, Laboratory Teaching, Fluid Mechanics, Virtual Reality, Gender, Internet of Things

This paper presents the development of a prosthetic foot designed by engineering-school students. A complete workflow from needs definition to the production and testing was performed. The standards for adults were adapted to children, then a pre-design was performed, and a numerical model was realised to perform numerical testing. The production was carried out through additive manufacturing and the printed prosthetics were tested in flexion, and then in a motion analysis room. This project was aimed at making students put into practice their ability to design and test a mechanical product in a biomechanics context. Their learning outcomes were assessed during their oral presentations, their written reports and the testing session. Students gave positive feedback at the end of the semester about their feeling of the project.

Keywords: biomechanics; prosthetic feet; mechanical design; additive manufacturing; medical device

The purpose of this study was to explore the effectiveness of the teaching program of integrating the virtual prototype technology for students majoring in mechanical engineering. An activity involving the engineering teaching ideas of applying the virtual prototype technology to the design of NC machine tools was implemented for the study. It constructs the context-based teaching design along with a self-developed virtual learning environment. To describe the improvements in the students' understanding of NC machining course, a comparison was performed with the class teaching based on different teaching modes to learn the designed task. We used the statistical hypothesis test to evaluate the validity of the proposed teaching method according to the survey data from 58 engineering students participating in this applied research, with a qualitative methodological approach using a combination of case study and survey. We also evaluated students' response towards the research topics to investigate its teaching-learning effectiveness and acceptance by student community. Findings from the study have implications for the improvement of NC machining course and provide a framework for the students to get comprehensive simulation and analytical optimization through NC machine tools designed by themselves. Students' feedback also revealed that students obtain more satisfaction and self-confidence, and demonstrated high positive attitude towards the proposed teaching method, and showed high perceived usefulness of the context-based teaching design to acquire the knowledge of NC machining.

Keywords: virtual prototype; human computer interface; NC machining; mechanical engineering; collaborative learning

Andrés Díaz Lantada   1814–1832   Engineering Education 5.0: Continuously Evolving Engineering Education

This study presents the concept of "Engineering Education 5.0", a future educational paradigm linked to a vision of engineering education characterized by a need for continuous evolution, as a consequence of a challenging quest for a more sustainable and caring future. In a way, this forthcoming evolution emanates from very relevant advances in engineering education achieved in the last decades and from a view inspired by the Sustainable Development Goals, but beyond the Agenda 2030 in terms of temporal framework. Besides, it outruns current emergent approaches and innovation trends, linked to supporting the expansion and application of Industry 4.0 technologies and principles. Engineering Education 5.0 transcends the development and application of technology and enters the realm of ethics and humanism, as key aspects of for a new generation of engineers. Ideally, engineers educated in this novel educational paradigm should be capable of leading and mentoring the approach to technological singularity, which has been defined as a future point in time at which technological growth becomes uncontrollable and irreversible leading to unpredictable impact on human civilization, while ensuring human rights and focusing on the construction of a more sustainable and equitable global society.

Keywords: Engineering Education; Industry 4.0; Engineering Education 5.0; Agenda 2030; Sustainable Development Goals

Pia Bøgelund and **Bente Nørgaard**   1833–1849   Investigating Required Group Dynamics and Motivational Strategies for High-Performance Study Teams

The objective of this article is to explore what are the group-related dynamics and motivational strategies for becoming a high-performing engineering student team in a university environment applying a problem – and project based learning (PBL) model. It reflects an interest in engineering students' motivation to learn in groups – a poorly researched area within Engineering Education in times of great educational, societal and environmental need for engineers who possess such collaborative skills and competencies. The theoretical framework is constructed by contemporary theories about relational dynamics (liquidating, maintaining or evolving ways of interaction), 6 strategies to support or inhibit motivation in collaborative learning and theories on high-performing teams. Empirically, the study is based on recorded real-time interviews and actions of three selected first-year engineering student teams' collaboration and interaction, with 5 or 6 students in each group. Theoretically, the article concludes that high-performing study teams are characterised by an ability to stay curious and draw learning and nourishment from internal differences, while still keeping an explicit learning focus. Being able to acknowledge and work with unresolved differences is an ability that puts the team on a constant evolving learning curve. Reflecting upon and being able to master 6 specific motivational strategies creates the most supportive and developing framework to do so. From an empirical point of view, we show how this plays out in three specific teams and conclude that our three engineering student teams are on their way to become high-performance teams, displaying qualitatively different versions of what an efficient study team looks like.

Keywords: high-performance team; group dynamics; motivational strategies; engineering students; PBL

Chan Choong Foong and **Peng Yen Liew**   1850–1861   Investigating the Reliability and Usefulness of Self- and Peer Assessments of a Capstone Design Project

There is increasing use of self- and peer assessments to assess behaviours of students working on group projects. This study aimed to explore the reliability and usefulness of self- and peer assessments during a capstone design project. A sample of 61 final-year undergraduate students aged 23 to 25 years old who were enrolled in Bachelor Degree of Chemical Process Engineering participated in the study. Students worked in groups of 5 to 6 members for 28 weeks to complete the project. Training was provided, and progress was monitored. Self- and peer assessments were conducted during the 6th, 14th and 22nd weeks. In each assessment, students rated their own behaviours and those of their peers using identical Likert scale questionnaires, and they also wrote feedback to themselves and their peers. Quantitative findings reported that, in the 6th week, students ranked themselves (mean = 3.98) significantly lower than how they ranked their peers (mean = 4.16). In the 14th week, students still ranked themselves (mean = 4.14) lower than how they ranked their peers (mean = 4.20). Last, in the 22nd week, students ranked themselves (mean = 4.24) equivalent to how they ranked their peers (mean = 4.24). For qualitative findings, feedback written to peers in the 22nd weeks was compared to self-assessment feedback from that week. Self- and peer observations on one's strengths and areas for improvement seem to converge both quantitatively and qualitatively towards the end of the project. It is also noted that both self- and peer assessment scores increased between the first and third assessments. The findings imply that students' behaviours improved while working on the capstone project. In conclusion, self- and peer assessments could be reliable and useful for chemical engineering students, and training students in how to conduct these assessments is essential to ensure successful implementation. Future qualitative research could identify how and why students gradually change their behaviours in long-term, team-based projects.

Keywords: peer assessment; self-assessment; capstone design project; chemical engineering; reliability; usefulness

Dongwook Hwang, Carlye A. Lauff, K. Blake Perez, Bradley A. Camburn and **Kristin L. Wood**   1862–1876   Comparing the Impacts of Design Principles for Additive Manufacturing on Student and Experienced Designers

Additive manufacturing (AM) continues to play an important role in product development. Often, AM is integrated into later stages of the design process for products during detailed design, manufacturing, and production. There is an opportunity to introduce AM during early-stage design, which could inspire new business models and services in addition to re-thinking manufacturing for products and artefacts. The research objectives of this work are to first develop AM Design Principle Cards, which include a set of design principles for AM, and then demonstrate the impact of the AM design principles on designers' ideation performance. An ideation experiment was conducted to show the impact of the AM design principles on novelty and quality of ideation performance between students and experienced designers, as well as self-reported reactions and knowledge acquisition in AM. The research demonstrates that the AM Design Principle Cards can serve as a useful and meaningful design tool to support knowledge acquisition, creativity, and innovation with AM during early-stage design.

Keywords: additive manufacturing; design principles; design experience; ideation tool

Biljana Panić, Ivana Kovačević, Mirko Vujošević and **Marija Kuzmanović**   1877–1888   The Impact of Cooperativeness Supply Chain Performances

In this paper we analysed the relation between cooperativeness as a personality trait of participants in a supply chain and the bullwhip effect. We explored the possibility of change participants' cooperativeness but we also showed the learning process of engineering students. In order to teach our students about behavioural causes of the bullwhip effect and to increase their awareness about the influence of their cooperativeness on decision making in the supply chain, we simulated decision making in the beer game performed by four groups of engineering students. The beer game is a role-play simulation game that lets students (or managers as well) experience typical coordination problems of supply chains. Participant cooperativeness is determined using a Social Value Orientation (SVO) questionnaire, applied before playing the game to classify them into cooperative and uncooperative ones and after playing the game to investigate changes of cooperativeness. Participants were assigned randomly to one of the two situations: a chain with and without sharing information. The experiment conducted twice – firstly with 20 engineering students, and secondly with other 22 engineering students. The results, showing lower costs within the team with cooperative behaviour tendencies and permission to share relevant information, point to the importance of the further study of the behavioural causes. Students realized that their behaviour influences the behaviour of others and how that can change the results of the team. After playing the game students filed SVO questionnaire again, and we showed that students who shared information increased their cooperativeness scores, while cooperative participants who couldn't share information decreased their cooperativeness scores, so we found that students can learn cooperativeness to achieve better supply chain results.

Keywords: bullwhip effect; cooperativeness; social value orientation; supply chain; learning

Jingxiao Zhang, Chuandang Zhao, Jun   1889–1900   Evaluation Framework for an Interdisciplinary BIM Capstone Course in
Wang, Hui Li and **Henk Huijser**   Highway Engineering

This study aims to develop an evaluation framework for improving interdisciplinary BIM (Building Information Modeling) education in highway engineering. The evaluation framework is designed based on the Context-Input-Process-Product (CIPP) model and applied in an interdisciplinary BIM capstone project at Chongqing Jiaotong University. Four project teams with a total of 52 students from 9 different majors were involved in the highway and its service area design after centralized training. Mixed research methods were used for data collection, including a questionnaire survey for students and semi-structured interviews for team leaders and instructors through purposive sampling. The results indicate that: (1) all students have a deep awareness and interest in learning BIM and joint design; (2) BIM software training and its theoretical knowledge should be incorporated into BIM capstone courses; (3) BIM coordination meetings in the design process play an important role in reducing model collisions and redesign work while the instructor's performance has no significant impact on this aspect; and (4) prior knowledge of teamwork experience has the greatest correlation with performance of joint design. This evaluative study provides a paradigm to evaluate and improve BIM capstone projects in highway engineering. Educators who are interested in BIM education and highway engineering can refer to this capstone course and its evaluation process.
Keywords: BIM; education; CIPP; highway engineering

Michelle R. Oswald Beiler   1901–1911   Design and Integration of Transit-Oriented Development in Transportation
                                            Education

Transit-oriented development (TOD) is an effective planning strategy that has continued to gain interest for over a quarter century since the term has been coined. TOD is a mixed-use development that concentrates on connecting spaces and infrastructure around successful transit service in order to provide high mobility. To prepare for continued implementation, TOD needs to be fully integrated into curricula to expose and attract the next generation of transportation engineers and planners. This study focuses on an evaluation of existing TOD pedagogical efforts across the nation in order to identify the level of integration. A survey is conducted on higher education programs throughout the United States in order to provide an update on module versus full course level integration and determine existing pedagogical methods/resources used in the classroom. In addition, a case study application focused on the development and implementation of a TOD module to a sustainable transportation engineering course at Bucknell University is provided with the goal of integrating the module into similar courses throughout the country.
Keywords: transit; education; pedagogy; sustainability; transportation; planning

Ana Fonseca Reyes, Luceny Guzmán,   1912–1923   Impact of Teamwork on Academic Performance of Engineering Students
Ángela Jasmín Fonseca Reyes and
Lizeth Del Carmen Gutiérrez Púa

The methods of collaborative learning are based on constructivism, understood as an equitable process, wherein each individual participates to produce a mutually desirable result, which promotes self-regulation. In this work, the influence of team-based learning (TBL) methodologies was studied. The effect of TBL on the learning of students in mechanical engineering and industrial engineering of the Universidad Del Norte, Barranquilla, Colombia, was analyzed. The investigation was carried out in the course of manufacturing processes for a sample of 348 students, specifically in the laboratory practice component, during three study periods. A quasi-experimental design was used, which involved three measurements: an individual quiz (IQ), a group quiz (GQ) and a final project (FP). The Comprehensive Assessment of Team Member Effectiveness (CATME) survey was used to determine perceptions of teamwork by students. Statistical analysis showed that the way in which TBL methodology is implemented develops students' skills influencing their academic performance and improving the scores obtained in assessment activities. Finally, students valued the contribution and interaction with their teammates as the most important aspects for team-based learning.
Keywords: feedback; learning methods; self-control; social interaction; spatial skills

Ásdís Helgadóttir, Halldór Pálsson and   1924–1937   Balancing Student Workload with Learning Outcome – The Search for
Guðrún Geirsdóttir   Suitable Assignment Format for a Fluid Mechanics Lab

In this paper, the authors describe different revisions to a fluid mechanics module at the University of Iceland where they aimed to find a suitable assignment format for the laboratory component. Traditionally, a full laboratory report is expected from every laboratory session. Students in the course, however, claimed that the laboratory component of the course was too time consuming and their learning from it was minimal. Therefore, attempts were made to design an assignment that would reduce student workload without decreasing their learning. The study covers five years of course revisions. In the first two years, students were required to submit a full report for each experiment, but in the following three years, students submitted a worksheet, short report or Excel sheet assignment. Students perceptions of each assignment format were assessed using the university midterm and end-of-term teaching evaluation surveys along with a laboratory-focused survey. In addition, a focus group interview with a group of students was conducted in the last year. The results indicate that alternative assignment formats outperform the full report in students' report of workload, learning gains and satisfaction with the laboratory component.
Keywords: laboratory teaching; mechanical engineering education; chemical engineering education; workload; assessment; assignment format

Vidanelage L. Dayarathna, Sofia Karam, 1938–1955   Assessment of the Efficacy and Effectiveness of Virtual Reality Teaching
Raed Jaradat, Michael A. Hamilton,   Module: A Gender-Based Comparison
Morteza Nagahi, Sayali Joshi, Junfeng Ma,
Omar Ashour and **Bouteina Driouche**

The concepts and topics of manufacturing systems design and analysis are usually taught using traditional lecturing, in-class problem solving, and project-based approaches. These concepts are not easy to grasp and can be tedious when taught by traditional methods. This study presents an innovative virtual reality (VR) based approach to teach manufacturing systems concepts. To illustrate the efficacy and effectiveness of VR technology in enhancing students learning concepts, a VR queuing theory teaching module is developed. The efficacy and effectiveness of the VR module are then analyzed for male and female participants to investigate the impact of the VR environment on female engineers in science, technology, engineering, and mathematics (STEM). Simulation sickness, system usability, and user experience tools were used to assess the efficacy of the VR module, and the queuing theory quiz, NASA TLX assessment, and post-motivation measures were applied to evaluate the effectiveness of the developed VR module. Both males and females indicated higher user satisfaction in terms of system usability. Female participants perceived higher user experience than their male counterparts. Both male and female participants experienced similar simulation sickness symptoms throughout the study. The quiz score indicated that students performed well in the conceptual section for both genders. The NASA TLX results suggested that participants required low perceived work effort in regard to performing the tasks in the module. The post motivation results confirmed that the VR module created positive motivation in learning the queueing theory for both male and female students. Overall, the efficacy and effectiveness measures affirm that both male and female participants perceived a similar experience in the developed VR teaching module.
Keywords: manufacturing systems; virtual reality; engineering education; underrepresentation of women; efficacy and effectiveness

Wen-Jye Shyr, Chin-Chung Huang,   1956–1966   Students' Acceptance of Applying Internet of Things in a Smart Agriculture
Chia-Hung Chen and **Jhih-Syuan Wei**   Course

This study applied the technology acceptance model (TAM) to an Internet of Things (IoT) smart agriculture course, and used IoT teaching module and textbooks. Taking the students at a technical high school as the objects, it helps students to develop IoT

concepts, improves students' learning outcomes, and achieves the teaching goals of the IoT smart agriculture course. This study adopted independent sample t test, reliability analysis, and regression analysis, and used SmartPLS to measure the structure models for analysis. The results include the applications of the technology acceptance model to the IoT smart agriculture course. The equipment used was IoT teaching module and textbooks, which has high learning satisfaction. There is correlation between the dimensions of the technology acceptance model, and all hypotheses are valid and achieve significant levels.

David Naylor, Mary Francis Stewart and **Lingqian Li** 1967–1975 Comparison of Online and In-Class Instruction in Introductory Fluid Mechanics

An introductory course in fluid mechanics has been delivered with the lecture component in online and traditional face-to-face (F2F) modes. Online and in-class lectures were delivered by the same instructor and the student learning assessments were identical. Students were surveyed at the beginning of the course to assess differences in the online and F2F cohorts, and near the end of the course to gather feedback. This paper reports a comparison of the main student outcomes and feedback for both modes. A statistical analysis of the course grades shows that the students' program had the most influence on academic performance. The effect of the mode of lecture instruction on student performance was mixed and depended upon the students' program: mechanical engineering students performed better with the F2F lectures, while industrial engineering students had superior performance with online lectures.

Utku Gulbulak, Atila Ertas and **McKenzie Cordell** 1976–1987 The Impact of Transdisciplinarity on Solving Complex Engineering Problems in an Ethnically Diverse Classroom

This paper studies a transdisciplinary (TD) research approach to undergraduate engineering education to examine alternative learning and consequently, to improve STEM learning outcomes. A paradigm shift in engineering education is required in response to job market uncertainties to mitigate unemployment and prepare students to tackle problems requiring TD knowledge, methods, tools, skills, and expertise from different disciplines and forming novel frameworks to catalyze scientific discoveries and innovations. The expected results of TD research and education are an emphasis on teamwork; collaboration; bringing together diverse science and engineering disciplines; developing and sharing concepts, methodologies, and tools; to solve complex scientific and engineering problems.

The objective of this study is twofold, first to assess the impact of the TD pedagogical approach on the learning outcomes of the ethnic minority students, second to implement and practice Collective Intelligence Management Workshop (CIMW) supported by Transdisciplinary Design Studio (TD²S) for Collaborative Research and Education (CORE).

Xiangyu Kong, Wenqi Lu, Qi Guo, Yihua Zhu, Fang Zhang and **Bin Li** 1988–1995 A New Approach for Engineering Education Reform of Power System

While Industry 4.0 is quickly transforming the modern industrial landscape, the traditional education model is facing significant challenges. In order to train the talents to meet the needs of new industrial development, this paper takes the course of electric energy production as an example and puts forward the operable teaching reform methods. First of all, according to the development trend and demand of power system industry, some critical issues of education reform are condensed. Secondly, based on the proposed new engineering teaching evaluation standards, a new approach for engineering education reform of power system are designed, and the teaching content, practical teaching methods and classroom teaching methods are improved. Through the comparison of actual education results, the effectiveness of the proposed method is verified. Finally, some useful concludes are provided in the paper.

Kyle M. Whitcomb, Z. Yasemin Kalender, Timothy J. Nokes-Malach, Christian D. Schunn and **Chandralekha Singh** 1996–2014 Comparison of Self-efficacy and Performance of Engineering Undergraduate Women and Men

There is a significant underrepresentation of women in many Science, Technology, Engineering, and Mathematics (STEM) majors and careers. Prior research has shown that self-efficacy can be a critical factor in student learning, and that there is a tendency for women to have lower self-efficacy than men in STEM disciplines. This study investigates gender differences in the relationship between engineering students' self-efficacy and course grades in foundational courses. By focusing on engineering students, we examined these gender differences simultaneously in four STEM disciplines (mathematics, engineering, physics, and chemistry) among the same population. Using survey data collected longitudinally at three time points and course grade data from five cohorts of engineering students (3,928 students) at a large US-based research university, effect sizes of gender differences are calculated using Cohen's d on two measures: responses to survey items on discipline-specific self-efficacy and course grades in all first-year foundational courses and second-year mathematics courses. In engineering, physics, and mathematics courses, we find sizeable discrepancies between self-efficacy and performance, with men appearing significantly more confident than women despite small or reverse direction differences in grades. In chemistry, women earn higher grades and have higher self-efficacy. The patterns are consistent across courses within each discipline. All self-efficacy gender differences close by the fourth year except physics self-efficacy. The disconnect between self-efficacy and course grades across subjects provides useful clues for targeted interventions to promote equitable learning environments. The most extreme disconnect occurs in physics and may help explain the severe underrepresentation of women in "physics-heavy" engineering disciplines, highlighting the importance of such interventions.

Eunjeong Park, Alexia Leonard, Jack S. Delano, Xiaofeng Tang and **Deborah M. Grzybowski** 2015–2029 Rubric-Based Assessment of Entrepreneurial Minded Learning in Engineering Education: A Review

Existing literature of entrepreneurial mindset (EM) assessment has focused primarily on measuring psychological constructs, and little has been reported on other forms of assessing EM. A rubric – an explicit set of criteria to assess a particular type of performance – is an important tool to directly assess students' development of the entrepreneurial mindset. Despite the impact of rubrics on assessing and improving engineering entrepreneurship education, there is currently a lack of systematic examination of rubrics as assessment tools used in entrepreneurial programs in engineering education. To fill this gap, this paper explores rubric-based assessment of entrepreneurial minded learning (EML) by examining (1) the underlying pedagogical approaches, models, and theories that contextualize rubrics-based assessment, (2) elements of rubrics relevant to the assessment of EM-related learning outcomes, (3) the benefits and challenges of creating and implementing rubrics according to educators' reported use, and (4) the implications of using rubrics to promote EML. Several databases and both national and international journals were systematically searched for rubric-based assessment of EML. According to our inclusion and exclusion criteria, this paper selects and reviews 23 studies of this kind. The major finding of this systematic review is that rubrics may offer a promising platform of assessment for entrepreneurial minded learning in engineering.