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Project-based learning (PBL) promotes development of critical thinking and problem-solving skills by allowing students to work in teams on real world projects. However, in spite of its effectiveness, the use of PBL in engineering classrooms has been limited due to the challenges associated with its design and implementation. Instructors have reported concerns regarding the amount of time required in administering PBL and difficulty in aligning projects with student workload preferences. While several studies have been conducted to examine the effectiveness of PBL in engineering courses, minimal research attention has been devoted to finding effective strategies for using PBL. Most recommendations in the literature have been primarily anecdotal. In this practitioner-focused study, we present an examination of a PBL engineering course and explicate techniques for implementing PBL. Using classroom observations, instructor interviews, student focus groups and surveys, we examine instructional approach and students' response to PBL. The findings offer several strategies for designing project tasks, sequencing projects, assigning presentation topics, and selecting readings in PBL course.

Keywords: project-based learning; instructor strategies; active learning

Even after formal instruction, students struggle with concepts in fluid mechanics, including situations involving pipelines with a changing diameter. Therefore, it is necessary to explore the misconceptions and reasoning that students have with pressurized pipeline flow. Using interview data from three different cohorts of students, this article addresses the following questions: (1) How do students conceptualize pressurized pipeline flow? (2) What misconceptions do they have and how can those misconceptions be explained by existing conceptual change theories? (3) Are those misconceptions consistent across multiple participant groups with varying levels of experience in fluid mechanics and across different problem sets? Answering these questions provides insight into an appropriate theory of conceptual change, which will in turn help instructors achieve conceptual change in the classroom. It is theorized that a combination of an ontological shift theory and "framework theory" provides a more complete understanding of students' misconceptions in fluid mechanics, and provides suggestions on how to implement schema training and active learning to facilitate conceptual change.

Keywords: fluid mechanics; FMCI; conceptual change; mental models; active learning; schema training

Miniaturized fluid mechanics and heat transfer systems have been developed for classroom learning of flow measurement, hydraulic loss, and heat exchanger concepts. This equipment produces measurable, predictable temperature and pressure changes using tap water across a narrow flow range. Herein the capabilities of the equipment, agreement with correlations, and evidence of suitability for classrooms are provided. Analysis of student comments, from open-ended survey questions given to a total of 52 students over two semesters, is generally positive with students finding added value from using the equipment.

Keywords: hands-on learning; miniature heat exchangers; industrial correlations; miniature fluid flow equipment

Engineering as a profession is becoming increasingly complex and competitive. New technologies (advanced telecommunications and computer-aided engineering), and reduced barriers to international trade have allowed corporations to move engineering activities into emerging economies. These factors have allowed corporations to "unlock" traditional forms of organizational integration and undergraduate engineering programs in universities in these developing countries are quickly approaching the quality of programs in western countries, vastly increasing the pool of engineers from which companies can draw. The reduced cost of operation in these emerging economies has put pressure on western countries to produce engineers that can encourage companies to keep high quality, technical engineering jobs local, instead of outsourcing. This raises the question: what are the attributes of a high-quality engineer, and what changes to the engineering curriculum need to occur to emphasize these attributes? In this paper, we examined the history of modern engineering education and the push toward an outcome based evaluation of

graduate skills. We identified which where the most important graduate outcomes in engineering practice, and outlined how engineering design project courses can be used to emphasize these attributes. Engineering design competitions were highlighted as an ideal source for projects when coupled with the teaching techniques of problem based learning (PBL) and cooperative learning (CL).

Benjamin B. Wheatley, Kristine M. Fischenich, Lisa M. Abrams Sheryl A. Sorby, Harlal Singh Mali, Anil K. Jain and **Tammy L. Haut Donahue**

An International Fellowship Experience for Engineering Undergraduates: Improving Technical, Teamwork, and Cultural Competency

The opportunity to partake in an international technical experience is rare for undergraduate engineering students. While these programs are not common, this international exposure provides highly valuable educational experiences for students. This work highlights the approach, goals, outcomes, and improvements of year one in a three-year program where students applied engineering methods in a developing country to improve the design and fabrication of a low cost prosthetic limb known as the Jaipur Foot. Specifically, six students travelled to Jaipur, India to partake in not only technical work, but to also gain insight into how cultural differences affect engineering practice and to learn about the appropriate use of technology in the developing world. In summary, students developed important practical skills, but perhaps more importantly they acquired valuable communication skills and an understanding of the greater clinical impact of their work. This work supports the notion that global competency for engineers should be obtained through direct experiences in a different culture.

Rosa Estriégana-Valdehita, Roberto Barchino Plata and **José-Amelio Medina-Merodio**

Educational Technology in Flipped Course Design

The use of technology to engage students and to provide them with tools to study autonomously is increasingly frequent in higher education. This paper outlines an experimental study that analyzes the effectiveness of flipped classroom design, and argues how the use of technological, educational resources such as videos of educators teaching, interactive materials, simulators, virtual labs and game-based learning have facilitated the use of class time for active learning and discussion.

The study was conducted in several academic years with groups studying Fundamentals of Computer Technology, a core subject in the first year of the Computer Engineering and Information Systems degree courses. We analyzed data collected from online activities on a learning platform created from scratch, from classroom activities and from attitudinal and satisfaction surveys. We compared the evolution of outcomes between the 2009–2010 and 2015–2016 academic years. The methodology followed a quantitative design with control and experimental groups, and descriptive statistical techniques were used.

The results obtained show that learning achievement and performance in terms of qualifications were higher in the experimental groups, where the flipped classroom approach using technological resources was adopted, than in the control groups, where the traditional lecture approach was used. A significant positive effect on participation, engagement and student satisfaction was also identified.

Denise R. Simmons, Yincheng Ye, Nathaniel J. Hunsu and **Olusola O. Adesope**

Development of a Survey to Explore Out-of-Class Engagement of Engineering Students

This study describes the development and validation of the Postsecondary Student Engagement (PosSE) Survey, an inventory designed to assess indicators of affective engagement associated with student disposition toward their academic discipline, career and themselves, other students, and faculty. The PosSE Survey was developed to elucidate the relationships between STEM students' out-of-class activity involvement, factors that influence such involvement, and their perceptions of their learning outcomes. Two rounds of reliability analysis and exploratory factor analysis (EFA) were conducted on data from 129 survey respondents. The first analysis examined the internal consistency of the original items developed to assess each construct of the PosSE Survey and validate the instrument. We re-analyzed Cronbach's coefficient alpha of each construct on the instrument after the EFA to examine how the items and related latent constructs were improved in terms of internal consistency reliability. These analyses provided results that helped develop and validate the 27 items and 7 factors of the PosSE Survey. Future work requires wider survey distribution and larger sample sizes so that data can be used to create a more nuanced profile of student engagement, particularly among underrepresented student populations.

Hsiu-Ping Yueh, Yi-Lin Liu and **Chaoyun Liang**

Multidisciplinary Learning: Impact of Internal and External Factors

This study examined the moderating effect of scientific literacy between self-regulated learning and quality online material, as well as that between teaching effectiveness and multidisciplinary learning outcomes. The study also tested how quality online material mediated the effects of scientific literacy, self-regulated learning, and teaching effectiveness on multidisciplinary learning outcomes. Survey data was collected from 242 participants to determine the appropriate scale structure by performing an exploratory factor analysis. Another set of data, comprising 922 participants, was also analysed to confirm the factor structure and build a predictive model. The results indicate that the mediating effects of quality online material on the relationship between scientific literacy, self-regulated learning, teaching effectiveness, and learning outcomes were supported. Quality online material and teaching effectiveness were identified as the most influential variables on multidisciplinary learning outcomes. In addition, scientific literacy was not only an effective moderator between self-regulated learning and quality online material, but also moderated the relationship between teaching effectiveness and multidisciplinary learning outcomes.

Klavdiya Bochenina, Anna Bilyatdinova, Alexey Dukhanov and Gerassimos Athanassoulis

Implementation and Deployment of Transdisciplinary Learning Environments during Short-term Educational Events on Computational Science

Short-term educational events having the duration from several days to several weeks bring together participants from different educational institutions with diverse backgrounds and provide a unique opportunity to foster their collaborative competencies beyond a familiar environment. In this paper, we consider a short-term event as a basis for deployment of Transdisciplinary Learning Environment (TLE) intended to familiarize participants with how to solve multi-domain ill-defined problems in groups. Summarizing our experience in organizing several Russian and international Schools in Computational Science with more than 200

participants over 2008–2016 years, we introduce the principles of short-term TLE design and deployment and describe knowledge transfer processes which take place in them. The objective of the paper is to present and discuss the results obtained during the implementation of short-term TLEs for students in Computational Science and to create a basis for purposeful formation of learning environments aimed at mastery of transdisciplinary competencies of engineering students. The main conclusions from the study are as follows: (i) groups of participants with different background can cope with transdisciplinary problem after being immersed into TLE, (ii) consequence of activities during team work corresponds to those in the proposed knowledge transfer cycle, (iii) previous research experience of participants influences their flexibility in the choice of an area during a short-term team work.

Keywords: knowledge transfer; transdisciplinarity; short-term educational programs; learning environments; computer engineering education

This paper describes the creation of a Transdisciplinary Design Studio (TD^{2}S) for Collaborative Research and Education (CORE) in the Department of Mechanical Engineering at Texas Tech University and a study of this pedagogy for undergraduate engineering students. More specifically, this paper highlights a project-based TD design class which encouraged small student research groups to take on new behaviors of work—collaboration and teamwork—to solve complex problems. To create engagement in the class, an active learning and design-based research pedagogy was incorporated. Three main components (digital learning, creativity tools & techniques, and domain experts) of the TD design studio were examined for their contribution to student learning. We highlight the overlooked role of transdisciplinary design training in the undergraduate research experience and make specific reference to the impact of these pedagogical techniques on the learning outcomes for both Caucasian and under-represented minorities. Students' collaboration and creativity skills (TD skills) were tested and the results are presented. The ultimate goal of the TD class is to promote the creative, innovative, and divergent thinking of students.

This research study validated that TD-methods support the learning of underrepresented groups: transdisciplinary practice showed positive impact on underrepresented minority students' learning.

Keywords: transdisciplinarity; engineering education; transdisciplinary design studio; collaborative research; collective intelligence

Undergraduate engineering laboratory courses are designed to increase students' hands-on capabilities through application of theoretical knowledge. However, a laboratory manual may lack any connection to prior content, and expectations for thoughtful, developed writing are minimal. In this article, an instructor's implementation of a collaborative project to build Rube Goldberg machines combined with the course laboratory reports presented via blogs has been evaluated. An end-of-semester survey was conducted with the 18 students in the course and results are discussed along with the analysis of blog comments and student products. Overall, the intervention was deemed successful as a means to improve students' engagement, learning, and collaborations, despite some students' concern that blogging may not have improved their learning.

Keywords: circuits lab; writing; blogging; blog; digital writing; Rube Goldberg; engagement; collaboration, interdisciplinary skills; laboratory report

The case study presented in this paper was motivated by a teacher's desire to understand better the conceptual difficulties his students were experiencing with the topic of the Mohr Circle in a materials engineering course. To gain such an understanding, a phenomenographic study was undertaken based on student interviews. The findings of the study identified four categories of qualitatively different conceptions about the Mohr Circle that were evident among the students. These, together with a number of subcategories, provided a conceptual structure for modifying the way the course was taught and also highlighted particular aspects of the topic that required pedagogical attention. Although the study derives from a specific group of students and relates to a specific context, the insights reported in the paper may have relevance to other contexts and groupings of students. In particular, it demonstrates the utility of phenomenography as a useful methodology in research-led engineering education.

Keywords: engineering education; student-centred education; evidence-based education; stress analysis; failure analysis; phenomenography; Mohr Circle

In this study, we explored engineering doctoral students' motivations for selecting their research topic. The extent to which individuals are intrinsically or extrinsically motivated and the autonomy they have to make their own decisions has implications for their enjoyment of and success at a particular task. Given the importance of motivation, we sought to address a gap in the understanding of how doctoral students in engineering decide on a particular problem to study. Our findings are based on interviews with students with varying past educational and professional experiences that enable us to capture a wide range of motivations for engineering PhD students' research subject decisions. We found that the majority of students interviewed reported some form of extrinsic motivation guiding their decision, though these students varied in their autonomy to select their own topic. Of the students who reported intrinsic motivations for their research topic selection, many had extensive prior work experience that informed their topic choice. Funding played a major role in shaping students' project decisions, which is reflective of the scale and expense of much of engineering work. However, our findings suggest there are a number of opportunities for students to identify research topics in which they personally perceive as important and interesting.

Keywords: returning students; doctoral research; motivation; self-determination theory

Self-efficacy is critical for academic success. Self-efficacy theory suggests that the social setting and problem format can influence self-efficacy. While robust studies assessing students' self-efficacy and its relation to other academic outcomes have been undertaken, little is known about the relation between self-efficacy and competence on specific problems and how problem format and implementation type relate to self-efficacy. 94 conceptual questions in three formats (interpretation, ranking task, and multiple-choice) were developed through an iterative research-based effort. Ten university faculty implemented questions with their students in one of five types (closed-book exam, take-home exam, in-class quiz, homework, and group discussion). In total, 569 individual students responded to 2,006 questions. To capture item-specific self-efficacy (ISSE), students were asked to rate their confidence immediately after they had answered individual questions, on a 10-point scale. It was found that students with similar performance self-reported a wide variance of self-efficacy and that many student answers lacked correspondence between self-efficacy and performance. Results of multivariate analysis of variance (MANOVA) revealed that student performance differed according to question format and implementation. Students performed best on interpretation questions and they had the highest ISSE and percentage correctness for problems completed in groups. The findings support that interactive learning can contribute to student competence and self-efficacy.

Keywords: self-efficacy; students' competence; problem format; implementation type; engineering education

Jean-Luc Martel, Kenjy Demeester, François Brissette, Annie Poulin and **Richard Arsenault** 1307–1316 HMETS—A Simple and Efficient Hydrology Model for Teaching Hydrological Modelling, Flow Forecasting and Climate Change Impacts

Hydrological models are commonly used to forecast streamflow and for climate change impact studies. There is a wide range of hydrology models using lumped conceptual approaches all the way to more physically based distributed algorithms. Most of these models come with a steep learning curve before they can be used efficiently by the end user, and they can be tricky to calibrate appropriately. Only a small number of hydrology models can be considered easy to set up and use, and even fewer provide their source code for easy modification to be tailored to individual needs. These drawbacks make it difficult to use these models in educational applications. The goal of this paper is to introduce a very simple, yet efficient, lumped-conceptual hydrological model designed to address the above problems. The MATLAB-based HMETS hydrological model is simple and can be easily and quickly set up on a new watershed, including automatic calibration using state of the art optimization algorithms. Despite its simplicity, the model has proved to perform well against two other lumped-conceptual hydrological models over 320 watersheds. HMETS obtained a median Nash-Sutcliffe Efficiency of 0.72 in validation, compared to 0.64 for MOHYSE (similar structure) and 0.77 for HSAMI (more complex structure). The model's source code is freely available and includes an optional simplified user interface. A climate change impacts simulation tool using the constant scaling downscaling method is also incorporated to the interface. HMETS has been tested in the Construction Engineering Final-Year Project for a group of 60 undergraduate students.

Keywords: teaching hydrological modelling; rainfall-runoff model; lumped model; conceptual model; climate change impact studies

Keisha A. Villanueva, Shane A. Brown, Nicole P. Pitterson, David S. Hurwitz and **Ann Sitomer** 1317–1334 Teaching Evaluation Practices in Engineering Programs: Current Approaches and Usefulness

The evaluation of teaching is a critical aspect in higher education. There is substantial knowledge based on best teaching evaluation practices that can be used, yet there is a lack of research regarding teaching evaluation practices that are used specifically in engineering programs. This research characterized teaching evaluation practices within engineering programs across the country, to understand and assess the current state of practice. Three research questions were explored: (1) What teaching evaluation practices are used in engineering programs? (2) Which practices are used for formative and/or summative purposes? (3) What practices do engineering faculty report as useful? An exploratory sequential mixed-method design, utilizing interview and survey methods was used. In the qualitative phase, data were collected using semi-structured interviews followed by the quantitative phase, which included the development of a survey to more fully understand the evaluation practices of the interviewed participants. Thirty-four educators, including course instructors, department heads, and program coordinators in engineering programs participated. The result of this study showed that end-of-course student evaluation of teaching (SET) is the most common approach. In addition to SET, other approaches to teaching evaluation include classroom observation by peers or non-peers, evaluation of classroom materials, and student mid-course evaluations. It was also identified that the formative practices used mainly to gather student feedback or to improve faculty teaching are useful to the participants. Although there is substantial interest in improving teaching evaluation practices, generally current practices are still much different from identified best practices such as evaluating active learning approaches in the classroom, constructive alignment of outcomes, activities and assessments as well as the frequency and quality of feedback to students. The teaching evaluation system in engineering programs can be improved when educators become aware of and choose to adopt approaches that have been demonstrated to improve teaching and student learning.

Keywords: teaching evaluation; formative evaluations; summative evaluations; engineering; higher education

Lung-Sheng Lee, Hui-Min Ko and **Mei-Tyng Wang** 1335–1344 Quality of Accreditation Services for Engineering Programs

Accreditation of degree-granting engineering programs has been conducted for a decade in Taiwan and has contributed to raising the quality of engineering education. While quality is closely linked to stakeholders' satisfaction, this study aimed to answer how the accreditation stakeholders consider the quality of accreditation services. We employed a PZB model comprising five service gaps and five constructs to analyse service quality, and surveyed 230 program supervisors that applied for accreditation (consumers) and 218 accreditation assessors (service providers). Consequently, the following gaps are found in the PZB (Parasuraman, Zeithaml and Berry) model: (1) There is a gap between the assessors' "perceived consumer expectations" and the program supervisors' "expected services"; in particular, the two-group gaps on "IEET accreditation increases graduates international recognition and generates substantial benefit" and "assessors show respect for others while undertaking their accreditation tasks" are large. (2) There is a gap between the assessors' "perceived service quality specification" and "the provision of service" (i.e. Gap 3 exists); and the most influential construct is "Reliability". (3) There is a gap between the program supervisors' "expected services" and "perceived services" (i.e. Gap 5 exists); in particular, the two-side gaps on the "IEET accreditation criteria reflect international trend" and "IEET reviews help programs improve the quality of education" are large and it indicates that the quality of accreditation services have not yet met the expectations of the assessed programs. (4) Insufficient confidence in the reliability of accreditation criteria and the provision of services. The results can be used for reference to improve engineering program accreditation practices, especially under the Washington Accord, and the process of which this study employed can be used to examine the service quality of other institutional and program accreditation.

Keywords: SERVQUAL scale; PZB model; service quality; program accreditation; meta-evaluation

Miloš Milić, Siniša Vlajić, Ilija Antović, Dušan Savić, Vojislav Stanojević and **Saša Lazarević** 1345–1360 Software Quality Standards and Lean Approach in Teaching and Learning Programming

The aim of this research is to improve the process of teaching and learning programming. We have considered ISO/IEC 9126 software quality standard and the Lean software development method applied to the process of teaching and learning programming. Taking into account that each software system is characterized by the software syntax correctness, software semantic correctness, and software quality, we argue for incorporating a software-metrics driven practice in the process of teaching and learning programming. In this context, each software system should be in compliance with a software development process. The fundamental principle applied in Lean programming education process is the detection of waste (in terms of software quality violations, partially done work, motion, and defects) in the education process. In this way, it is possible to improve the process of teaching and learning programming through a continuous inspection and improvement. We have developed a software tool in order to improve the process of teaching and learning. To evaluate this approach, we conducted an experiment with a total of 30 undergraduate students in which we investigated the violations of software metrics in the students' software projects. Although the number of participants in the experiment was limited, our findings confirmed that software quality standards and the Lean software development method can be successfully applied to the process of teaching and learning programming.

Keywords: programming; software quality; software metrics; ISO/IEC 9126; lean; education

Fatih Gurcan and **Cemal Kose** 1361–1368 Analysis of Software Engineering Industry Needs and Trends: Implications for Education

In modern day software development environments, analysis and understanding of the emerging industry needs is of strategic importance for a more effective software engineering (SE) education that is innovative and responsive to changing industry needs. Considering the demand for well-trained software engineers in the near future, an empirical study was performed on SE job postings in order to identify the emerging needs and trends in the software industry. The methodology of this study was based on

semantic topic analysis implemented by latent Dirichlet allocation (LDA), a probabilistic generative approach for topic modeling. The findings of the study indicated that, the software industry has a wide spectrum in terms of professional roles, responsibilities (in-demand skills) and combinations of programming languages. Each of the professional roles is profoundly based on specific skill sets that reflect the dynamics of the software industry. Also, the topics discovered by LDA highlighted a broad range of the characteristics of the SE, such as contemporary trends, demands, skills, tools, platforms, methodologies, and technologies that indicate the level of progress in this dynamic field. In light of these findings, an innovative academic curriculum for SE education can be designed consistent with the emerging needs and trends in the software industry. In this regard, the findings can provide valuable implications for the industry, academia, and SE community to close the gap between the industry needs and the current SE education.

Keywords: software engineering education; software engineer skills; software industry needs; topic modeling; latent Dirichlet allocation

Branislav Stevanov, Darko Stefanovic, Andras Anderla, Srdjan Sladojevic and **Nemanja Tasic**   1369–1379   New Approach to Information Systems Engineering Study Program to Meet Industry Expectations

Information system engineering is a complex discipline which involves learning different skills, from both technical and organizational point of view. At the Faculty of Technical Sciences, Novi Sad, the initial information system engineering study program has been changed with the goal of improving knowledge quality of future engineers. The reformed information system engineering study program combines lessons and lectures, studying and usage of a world class information system, workshops and students practice in enterprises (internship). The work of the fifty newly employed engineers in five information technology companies has been assessed for the sake of exploring the benefits of the reformed study program. Half of them studied in accordance with the initial study program, while the other half studied according to the reformed one. Data have been gathered via the questionnaire consisted of eleven questions, which tested the employer's satisfaction with their work. The answers have been statistically analysed and subjected to data mining techniques in order to evaluate the improvement of the engineers' skills. Three out of eleven questions are in correlation with the reformed study program. The given answers indicate that the engineers' knowledge gained at this program is significantly better and, thus, put in better use within the company they work for.

Keywords: improvement; information system engineering; learning environment; study program

Wen-Jye Shyr, Chien-Fu Chiou, Fu-Chun Yang and **Po-Chi Li**   1380–1385   Energy Management Competency Development based on the Internet of Things (IOT)

This study identified the competencies requirement for university students in energy management based on the Internet of Things (IOT) technique. First, three experts in the energy management and IOT field were interviewed, and a list of professional competencies was concluded. Then, 11 field experts were invited as subjects. Using the Delphi technique, questionnaires were designed to assess competency indicators for energy management based on IOT. The data collected from the questionnaires were analyzed using a non-parametric Wilcoxon signed rank test. Finally, this study concluded 34 professional competencies under five dimensions for energy management based on IOT. The findings could provide a valuable reference to educators in the field of engineering and technology education who are involved in training and development programs.

Keywords: energy management; Internet of Things (IOT); competency analysis

1386   Guide for Authors