Volume 38 Number 1 2022 ISSN 0949-149X

Contents

Section I
Special Issue
Designing Engineering Design Education in Canada

Guest Editors
Christopher Rennick, Ada Hurst, Steve Lambert, Meagan Flus – University of Waterloo, Ontario, Canada

The Canadian Design Workshop (CDW) is a new biennial workshop – held in partnership with the Clive L. Dym Mudd Design Workshop – that aims to investigate and share information on design education and research unique to Canadian institutions, focusing on elevating engineering design education and research within the Canadian context. The Canadian engineering education and research landscapes presently share commonalities and important differences from the landscape typically explored during the Clive L. Dym Mudd Design Workshops. This paper discusses the logistics of running the inaugural workshop (CDW1), including challenges and opportunities afforded by the virtual offering. A thematic analysis of the presentations and ensuing discussions during the workshop reveals a number of recurring themes across all sessions, including transdisciplinarity, sustainability, the design studio pedagogy, teaching of design in the ''middle years'' of engineering programs, and challenges in design education. The paper concludes with a reflection on the first offering of the workshop and implications for the future of CDW.

Keywords: design; design education; design research; network; community; undergraduate

Many Canadian engineering faculties employ a first-year design course. Offering a large-scale, realistic and valuable design experience to students beginning to learn about engineering is challenging. In 2020 the Faculty of Engineering (University of Alberta) introduced a new first-year design course for 1200+ qualifying year students: Introduction to Engineering Design, Communication, and Profession. The course is founded on four principles: engineering design is a distinguishing and core feature of engineering practice and education, transdisciplinary engineering design has a common process, sustainability is a key societal goal and integral to engineering design, and the communication of the evaluated design proposition is a necessary step towards design implementation. The course objectives are to introduce first-year students to the transdisciplinary design process and demonstrate differences between the engineering and traditional science programs. The course design had four additional requirements: (1) meet the needs of all our programs; (2) be taught by instructors from each of our disciplines (supporting transdisciplinarity and discipline ownership); (3) engage applied learning; (4) use the design process to solve a community-based problem. The course implementation was supported by two co-lead instructors, the continued involvement of a third design instructor (course co-creator), eight guest instructors (representing all Faculty programs and the provincial professional association), and ten teaching assistants from both engineering and industrial design programs. All course materials (lecture slides, online resources, project descriptions, assessments) were developed in advance. Even as we were implementing this new course, we were collecting midterm feedback, reflecting on and adjusting the course in real-time, and planning the next iteration using a continual improvement process. At the time of original submission, the aim of this paper was to provide insight into the course development, implementation and lessons learned through its delivery. However, with the COVID-19 pandemic, many more challenges faced the instructional team; these are also detailed in this paper.

Keywords: large classes; first-year; design course; first-year engineering; transdisciplinary; implementation; course continual improvement

This paper describes the implementation of a short duration, design-build-test project for first and second year students where teams were tasked with creating a functioning scanning tunneling microscope. The activity was scaffolded to ensure students could handle the demands of such a complex activity, while making sure that all students could experience some measure of success through specific tasks. This ''Engineering Design Day'' activity sought to provide experience in engineering design early in students' academic careers as a means to improve their design self-efficacy, show them connections with their classroom learning, and provide an authentic opportunity to work in teams. To evaluate the activity, the Engineering Design Self-Efficacy Instrument was given to students before taking part in the activity, and again at the end of the semester to assess whether there was any growth in student self-efficacy in conducting engineering design. The results showed a statistically significant increase in student confidence and motivation in conducting design, and in their expectations of success at design, while there was no change in their anxiety regarding design. Through examining responses, students enjoyed the activity, they were able to practice working in a team and they were engaged with the design process throughout. These results show that design activities of shorter duration than a typical course project may lead to positive change in students engineering design self-efficacy beliefs.

Keywords: design practice; experiential learning; studio; engagement; self efficacy; teamwork

Section II
Contributions in: Spatial Skills, Embedded Systems, Sustainability, Personalized Learning, Engineering Identity, Depth of Discipline, Virtual Reality, Challenge-Based Learning, Cooperative Programs, Assessment, Academic Dishonesty, Depth vs. Breadth, Leadership, Entrepreneurship, Service Learning, Laboratory Work

Spatial skills are fundamental to learning and developing expertise in engineering. This paper describes a new virtual and physical manipulatives (VPM) technology that this research team recently developed to enhance undergraduate engineering students' spatial skills. This technology consists of ten manipulatives spanning a variety of levels of geometrical complexity. Each manipulative is authentic due to its real-world engineering applications that were chosen to stimulate student interest in engineering. A computer program was developed to connect virtual and physical manipulatives, allowing students to receive spatial training anytime, anywhere through the Internet. Quasi-experimental research, involving an intervention group (n = 37) and a control group (n = 34), was conducted. Each group completed a pre- and post-test using the same assessment instrument that measured students' spatial skills. Normality tests were conducted. The results show that the data involved in the present study did not have a normal distribution. Thus, non-parametric statistical analysis was performed, including descriptive analysis, correlation analysis, and Mann-Whitney U tests. The results show that the mean value of normalized learning gains is 41.2% for the intervention group, which is 33% higher than that for the control group (8.2%). A statistically significant difference exists between the intervention and control groups in terms of normalized learning gains ($P < 0.01$). The new VPM technology developed from the present study has a medium effect size (0.34) on improving students' spatial skills.

Keywords: spatial skills; undergraduate engineering students; new virtual and physical manipulatives (VPM) technology

This work is a case study of teaching Embedded Systems course using project based learning method. Instead of delivering lectures coupled with lab demonstration on commercial embedded systems platform, this study takes a blended approach. A group of two or three students are assigned a design project at the start of semester. Theoretical foundation is laid through short lectures and demos; in lab, sessions students perform various activities using a commercial microcontroller board and are introduced to PCB design workflows and while they continue to work on their design project; in the last leg of semester students continue to work on their project in self-directed learning as a team. Projects of applied nature are considered to keep the students motivated. Direct and indirect assessment methods demonstrate that the design project approach not only increases the interest of students but also provides them with necessary confidence and prudence to design and implement functional prototypes. The detailed implementation plan is included to assist others who are teaching this/similar courses.

Keywords: embedded systems; engineering design thinking; micro-controllers; project based learning

To embed the phenomenon of sustainability in engineering education, there are few practices to think about and put into implementation. This article attempts to answer a pedagogical question about developing a teaching and learning practice for knowledge creation and competence. To realize this practice, the notion of the intelligent building has been addressed within the sustainability domain by piloting systems thinking pedagogy that incorporates learning tasks like cases, design modules, projects and is facilitated by guidance, feedback, and critique. The process utilizes the University of Ottawa (uOttawa) campus buildings as a "real-space sustainability lab" for developing learning content and collecting data for engineering design projects as part of teaching four related undergraduate courses. Gathered data from the questionnaires, interviews and observation clearly show that unleashing engaging activities into phenomena- and project-based learning may significantly improve student analytical thinking, reflective judgment, and self-efficacy.

Keywords: phenomenon- and project-based learning; sustainability; engineering design; intelligent buildings; systems thinking; knowledge creation; reflective practice

The rapid development of big data and artificial intelligence has brought impact on every aspect of people's lives. However, college students' education is still relatively traditional in that all students receive the same instruction, which hinders the improvement of students' performance. Students need more personalized teaching based on fast-developing technology. This paper introduces the design and implementation of an intelligent education prototype for an electronic systems course, and 89 students were given customized learning based on this prototype. The intelligent education prototype is based on the teaching platform to assist education. On the one hand, it provides students with various teaching resources. On the other hand, it makes statistical analysis based on the behavior data of students on the platform, so as to assist teachers in adjusting teaching strategies. To verify the effectiveness of our teaching method, we compared these students' final scores with the scores of other students who used traditional teaching methods. Student performance is assessed using examination results. The results indicate that the average score of the students who used the intelligent education prototype is 6.3 points higher than those who used the traditional teaching mode. The prototype proposed in this paper provides a reference for improving online education and is expected to positively influence the teaching of other courses in the future.

Keywords: data analysis and visualization; electronic systems; intelligent education; personalized learning

Women enter Science, Technology, Engineering, and Math (STEM) occupations that are commonly associated with helping and caring (e.g., health and life sciences) at much higher rates than engineering occupations. Girls interested in STEM might be unaware of the opportunities that engineering offers to help others. In this study, elementary and middle school-aged girls in the United States attended a one-day outreach event focused on environmental engineering, where they participated in hands-on activities. Participants were placed in either the caring (treatment) or control condition, where those in the caring condition heard

explicit messages about engineering as a caring profession and those in the control condition did not. Before and after the outreach event, participants (n = 88) completed the Engineering Identity Development Scale (EIDS). Participants in the caring condition had higher occupational identity following the outreach event as compared to participants in the control condition (post-survey), indicating a better understanding of the engineering profession. Additionally, the engineering aspirations of middle school participants were positively impacted as compared to elementary participants. Explicit messaging about caring can help to rectify misperceptions of the engineering profession and to improve girls' understanding of engineering. Additionally, our findings suggest that such outreach events are important for the development of engineering identity in middle school girls and can encourage their engineering aspirations.

Keywords: engineering identity; caring, K-12 outreach; environmental engineering

Depth of Discipline as an Influencing Factor of Engineering Identity 145–157

Jenna Johnson, Lesley Strawderman, Reuben Burch, M. Jean Mohammadi-Aragh and Jennifer Easley

In this study, we explored the relationship between depth of discipline and engineering identity. Undergraduate engineering identity scores are of importance as engineering identity is necessary for educational persistence to graduation. We explored relationships between depth of discipline and engineering identity by surveying engineering students at higher education institutions in the United States and assessing their self-reported engineering identity and demographic variables. Findings indicate that engineering students enrolled in discipline-specific engineering degrees while also pursuing a specialization or concentration possess slightly higher engineering identity than students not pursuing a specialization or concentration. Additionally, this study found that the construct of interest, a component of engineering identity, is more related to depth of discipline. This is an interesting revelation, as the construct of interest is a required prerequisite for authoring an engineering identity.

Keywords: engineering identity; depth of discipline; breadth vs. depth; engineering retention; educational persistence; interest construct

Development of Interactive Textbooks by Applying STEAM and Virtual Reality Concepts 158–170

Chih-Chao Chung, Bo-Yuan Cheng, Yuh-Ming Cheng and Shi-Jer Lou

This research aims to explore the impact of STEAM on VR-based interdisciplinary courses and the course satisfaction of students from a sci-tech university. To achieve the goal, this study took students taking interdisciplinary courses at a sci-tech university in south Taiwan as the research subject and carried out an 18-week "STEAM course about the development of VR-based textbooks" through small-group cooperative learning. To investigate the impact of the STEAM course and the course satisfaction of students, this study adopted both quantitative analysis and qualitative analysis, such as questionnaire analysis and file analysis, to evaluate students' performances on the products and grades. This study creatively combined the interdisciplinary and convergent thinking of STEAM with the course about the development of VR-based textbooks. Based on the student-centered and teacher-facilitated concepts, this study designed the STEAM course about the development of VR-based textbooks and found that most students think highly of the impact of STEAM, course satisfaction, and the assistance of VR-based textbooks to STEAM. Lastly, this study proposed some practical advice on how to combine STEAM with VR-based course teaching.

Keywords: STEAM; human-computer interactive; textbooks; virtual reality; education reform

Applying Challenge Based Learning to Teach Mass Transfer 171–180

Cristina Barrera, María Luisa Castelló Lucía Seguí, Ana Heredia and Jorge García-Hernández

In order to enhance undergraduates' understanding of mass transfer unit operations, Challenge-Based Learning (CBL) was applied in two courses on Transport Phenomena in the Food Industry. The courses are part of Agrifood Engineering Degree program at the Universitat Politècnica de València (UPV). After the lecturers explained the topic to the fourth-year students, they were given the challenge of preparing and solving cases of mass transport phenomena dealing with solid-liquid extraction and food drying. Students were divided into six groups of three or four students; each group chose a product to work with, and each group designed a flowchart with the main stages of the process based on the information gathered from varied bibliographical sources. The corresponding mathematical models were applied to characterize the flow and estimate the performance and efficiency. After that, students wrote short reports of the main steps followed to complete the task. The reports were presented to a panel of expert lecturers to provide feedback and recommendations. Specifically designed rubrics were employed by the panel to assess the impact of the methodology on students' subject-specific skills in addition to collaborative work, problem solving, time management and oral presentation skills.

Keywords: challenge-based learning; mass transfer operation; flowchart; oral presentation; recording; panel of experts; rubrics

Role of Cooperative Programs in the University-to-Career Transition: A Case Study in Construction Management Engineering Education 181–199

M. E. Al-Atroush and Y. E. Ibrahim

With the recent economic and technological rapid change, a major shift in the workforce nature is expected shortly. Construction management is currently focused on increasing productivity and optimizing structures costs. However, new management strategies rely on quality management, global manufacturing, building information modeling, and many others. Those new strategies require managers with soft skills and can operate in situations. With that in mind, cooperative education (Co-op) has a pivotal role in formulating the relationship between the universities and industry for better reflecting on the recently needed industrial requirements in curriculum content. In this paper, the role of the Co-op programs in university-to-career transition has been explored through a case study of the engineering management students of Prince Sultan University (Riyadh, KSA). Direct and Indirect assessment studies were performed to investigate the nature of the Co-op programs offered to the five student batches (2015–2019) of the Construction Management program (CMP), the students' gained experiences upon completion of the Co-op, the program's overall quality and efficiency, and the Co-op students' readiness to start their career. The 5A's indicators model has been used for the indirect assessment, while the SEF direct assessment tool was proposed to evaluate the student learning outcomes achieved by the end of the program, considering the evaluation of Employers, Faculty, and the students' self-assessment. The assessment results showed that the real-life experiences gained by Co-op students improved their job readiness. It also increased their chances of getting a job even before graduation. The study found that 70% of PSU construction management Co-op students got jobs through the Co-op. Nevertheless, the study also addressed several weak points associated with the offered Co-op, such as the unreliability of the employers' evaluation and ignoring the student self-assessment in the currently utilized direct assessment method.

Keywords: real-life experience; cooperative program; university-to-career transition; engineering higher education; assessment; case study

Invigilated Lab Exams as an Effective Strategy to Reduce Academic Dishonesty 200–210

María Sofía Martínez-García, Angel de Castro, Alberto Sanchez, Yasamin Ambrollahi and Javier Garrido

A new methodology assessment for the laboratory in engineering courses to reduce academic violations is proposed. It is based on invigilated face-to-face practical exams, and it is suggested as an alternative to the conventional laboratory assessment through student reports. This traditional method is sensitive to commit academic violations by students, like cheating, however, with the new proposal, it is drastically reduced. In the new assessment, the laboratory sessions are divided into theoretical-practical and tutorial sessions, when students work by themselves; and test sessions, when invigilated face-to-face practical exams are carried out to assess the laboratory part of the course. In these exams, the students must prove their knowledge in real-time with 100%

practical exercises. Before implementing this new methodology, the results in the course under analysis showed that cheating was becoming widespread with a clear increasing tendency. To test the proposed assessment, a comparison between the traditional and the new methodology laboratory assessment is accomplished in a Computer Architecture undergraduate engineering course. Descriptive and inferential statistics are used to analyze the influence of the new assessment on the learning results. The results show that with the new proposal the number of detected copies disappeared, and the withdrawal rate is reduced without having a significant influence on the final mark or the theory mark. Therefore, the new methodology assessment has removed the academic violations without interfering with the learning process of the students.

Keywords: assessment; computer engineering; engineering curriculum; academic dishonesty; computer architecture

Specificity of Discipline as an Influence on Entry-Level Engineering Occupational Alignment 211–223

Jenna Johnson, Lesley Strawderman, Reuben Burch, M. Jean Mohammadi-Aragh and Jennifer Easley

In this study, we explore how engineering specificity of discipline impacts occupational alignment of engineering graduates. Theoretically, we view this issue through the lens of the theory of occupational choice, as it relates to Social Cognitive Career Theory. The current state of research highlights the fact that many variables have been determined to influence engineering graduates' career decisions, though specificity of discipline has not been thoroughly explored as one of those variables. Empirically, historical National Survey of College Graduates data was examined for relationships and quantitative methods found a relationship between specificity of discipline and occupational alignment, with traditional engineering specificity having the most occupationally aligned graduates, followed closely by specific, and then general engineering.

Keywords: depth vs. breadth; occupational alignment; specificity of discipline; field retention

Uncovering the Hidden Curriculum of Leadership Education in Civil Engineering 224–236

Madeline Polmear, Nicholas Clegorne and Denise R. Simmons

The undergraduate experience is crucial for developing competencies and socializing future engineers into the profession. Leadership is a key outcome of engineering education that individuals are expected to develop for employment and advancement and that the profession is expected to demonstrate to address complex and interdependent societal challenges. Despite the growing inclusion of leadership in the formal curriculum in part due to accreditation criteria and industry pressure, there are persistent concerns over engineering students' workforce-ready leadership competence. This research examined how 13 civil engineering undergraduate students at four institutions in the United States define leadership and understand its development through the lens of the hidden curriculum. This framework was selected to conceptualize values and beliefs that are unintentionally transmitted to explore the potential misalignment between how leadership is formally taught and inadvertently learned. Thematic analysis of the semi-structured interviews indicated the varying ways in which students understand whether leadership can be learned, how leadership is defined, and who can lead. The findings are viewed through hidden curriculum to uncover their taken-for-granted beliefs and situated in the literature to show the tension between students' perspectives and contemporary leadership theory. Since students learn about leadership throughout their lives, inside and outside the classroom, this research does not attempt to trace the roots of these leadership beliefs. Instead, this paper uncovers students' tacit understandings of leadership to offer implications for educators and programs to recognize students' understandings and support their leadership development.

Keywords: leadership; hidden curriculum; civil engineering

Application of Entrepreneurial Minded Learning Design Projects to Develop First-Year Engineering Students' Entrepreneurial Mindset 237–252

Alexandra Jackson, Cheryl A. Bodnar, Scott Streiner, Kevin Dahm, Kaitlin Mallouk and Bruce Oestreich

The Entrepreneurial Mindset (EM) has become a widely studied topic in the field of engineering education, and is integral in student development and societal advancement. EM interventions into engineering curricula have been shown to positively encourage EM development; however, more research is needed to determine the longitudinal effects of these interventions. This study utilized an indirect assessment through survey responses and a direct assessment through grading rubrics to assess longitudinal outcomes in a first-year engineering program. The survey responses from the beginning and end of the academic year across two first year cohorts (n = 352 paired responses) indicated that students enter their engineering programs believing they already have a strong EM and leave their first year without much change. The direct assessment showed similar results, with both surveys and grading rubrics showing that students struggled the most with Ideation concepts. When analyzing these results in terms of the Kern Entrepreneurial Engineering Network (KEEN) 3Cs (Curiosity, Connections, and Creating Value), it was found that students performed the best in the aspects of projects that focus on Connections, and struggled the most with Creating Value. Overall, engineering students were shown to demonstrate minimal change in their EM over the course of their first-year, indicating the importance of EM integration into courses at all undergraduate levels as well as the significance of studying EM longitudinally. With these findings, educators and researchers can begin to modify first-year curriculum to help students with their ability to generate multiple potential solutions to problems. They can also work with their students to help them understand the value of their designs and the need for this focus as part of the design process.

Keywords: entrepreneurship; first year; project based learning; quantitative methods

Impact of Service Learning on Engineering Student Development 253–263

Jennifer Benning, Christopher Shearer, Stuart Kellogg and William Oakes

Traditional engineering curriculum can be enhanced by incorporating project-based service learning opportunities. One example of a pedagogical approach to this is the EPICS program, founded at Purdue University. Students at two universities with EPICS programs were quantitatively assessed for the program's impacts on critical thinking and intercultural competency, and the cognitive diversity implications and professional development outcomes were examined. Instruments for assessing these attributes include the Critical-thinking Assessment Test, Intercultural Development Inventory test, Hermann Brain Dominance Instrument, and focus groups, respectively. Improvements in critical thinking and intercultural competency were observed for students involved in EPICS for more than three semesters compared to both a first year and senior cohort not participating in the program. EPICS also engaged students with more diverse thinking preferences compared to a set of students engaged only in a traditional engineering curriculum. Professional development outcomes were also improved through involvement in the EPICS program. These studies indicate that there are clear benefits to students through their involvement in project-based service learning with the EPICS program, as well as to universities, by offering opportunities to engage and retain students with cognitively diverse problem-solving approaches.

Keywords: service learning; critical thinking; intercultural competency; cognitive diversity

Improving Student Learning Experience in Fluid Mechanics with Lecture/Lab Alignment and Post-Lab Discussion 264–282

Ásdís Helgadóttir, Halldór Pálsson and Guðrún Geirsdóttir

The paper explores curriculum development within the laboratory component of a fluid mechanics course taught at the University of Iceland. The paper addresses various steps taken to improve the laboratory work component of the course, such as, shortening experiments, aligning the schedule of laboratory work exercises with lectures, and adding postlab discussions. University midterm and end of term surveys were not effective to measure the consequences of the changes, so an additional survey focused on laboratory work was made. In addition, a student focus group interview was held three years into the study to further confirm and

deepen the findings on the effect of the changes made. All measurements indicate an improvement in the laboratory component by using the new schedule, in particular with the synchronization of lectures and experiments and with the addition of postlab discussions, where the results of all lab groups are compared and analyzed. Students reported increased satisfaction with the laboratory work, more appropriate workload, and better understanding of and learning from the laboratory work as compared to the past.

Keywords: laboratory work teaching; fluid mechanics; mechanical engineering education; chemical engineering education; workload; curriculum development