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Section I

Special Issue

Computational Thinking in Engineering Education for Addressing Complexity

Guest Editors

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With extremely rapid technological advancements, Computational Thinking (CT) skill is the most valuable entity in the 21st century for every active citizen on the globe. How to obtain this skill effectively is a focused matter of temporary education. This paper discusses a systematic, model-driven approach to introducing CT skills in Engineering Education (EE). The approach includes (i) a *conceptual model* covering relationships among robotics characteristics, Computer Science themes and basic CT attributes in the context of design and STEM task solving processes; (ii) a *design-based process model* defining the extended vision of these relationships, also covering learning resources and methods used and (iii) a *CT skill assessment model* based on Bloom taxonomy. The approach is validated and approved by designing and implementing the Goldberg machine.

Keywords: computational thinking skill; conceptual modelling; design process modelling; engineering and STEM education; Goldberg machine design

A wide variety of literature reviews on computational thinking (CT) have focused on education; however, there is still a lack of analysis regarding how global trends in this field affect developing countries. The aim of this study was to examine the evidence published between 1970 and 2024 on CT in educational contexts in order to identify challenges for the Colombian context, particularly in the training of computer engineering students. A Systematic Mapping of the Literature was conducted, using the PICOC methodology for formulating research questions, content analysis techniques, and PRISMA guidelines to guide the review process. The documentary search was carried out in the Scopus database, retrieving a total of 1,050 studies; after applying inclusion, exclusion, and quality criteria, a final set of 210 research articles was analyzed. The findings indicate that: (a) although CT shows sustained growth internationally, Colombia ranks among the countries with the lowest number of publications, highlighting the need to strengthen local research; (b) at the national level, the incorporation of CT into computer engineering programs remains incipient, posing a challenge for updating university curricula; and (c) the predominance of conference proceedings and international journal articles reflects global dynamism but also underscores the need for Colombia to reinforce its capacity to produce, publish, and disseminate scientific knowledge. This study is intended to be of value to researchers, educators, and policymakers interested in deepening their understanding of CT. It provides inputs to strengthen curricular processes, inform institutional decision-making, and foster new lines of research.

Keywords: computational thinking; systematic review; computer engineering; education

In higher education, the development of digital competences has become a central priority, particularly in science, technology, engineering, and mathematics (STEM) programs where virtual learning environments (VLEs) are increasingly integrated into academic practice. As institutions adopt these platforms, it is essential to understand how instructional design and the quality of student interaction contribute to strengthening digital literacy and computational thinking (CT) skills. This study examines the relationship between VLE use and the self-perceived development of digital competences, with special attention to the Central American context. A Small Private Online Course (SPOC) was implemented using the REDA-CT model (Strategic Resolution of Learning Challenges through Computational Thinking), which structured student learning around authentic digital challenges and promoted key CT sub-skills such as abstraction, decomposition, pattern recognition, and algorithmic reasoning. A quasi-experimental pretest–posttest design was applied with 1,008 university students from five institutions, and a qualitative analysis of pedagogical journals was conducted with a representative 10% subsample. Findings indicate that higher levels of student interaction in the VLE are associated with greater development of digital competences, particularly in information analysis, communication, multimedia production, cybersecurity, and problem solving. Students who engaged more actively with the REDA-CT framework also demonstrated more structured cognitive strategies aligned with its phases. These results support the integration of CT as a pedagogical model for promoting digital competences and fostering reflective problem solving in digitally mediated higher education environments.

Keywords: virtual learning environments; digital competences; higher education; digital literacy; competent students; digital learning environments

Gender disparities in STEM (Science, Technology, Engineering, and Mathematics) fields remain a significant challenge in education. This study explores the development of computational thinking skills through the use of a STEM Educational Kit combined with a visual programming environment (mBlock) among first-year students in Industrial and Systems Engineering in Peru. A quasi-experimental design with pre-test and post-test evaluations was applied to assess students' competencies in computational concepts, practices, and perspectives. Participants developed community-oriented projects that involved designing algorithms, interacting with sensors, and applying modular programming, under the guidance of instructors. The Mann-Whitney U test revealed no statistically significant differences between male and female students regarding the mastery of computational thinking dimensions. Nonetheless, female students exhibited a greater inclination toward achieving higher levels in conceptual understanding and practical application. The hands-on activities facilitated active engagement, creativity, and problem-solving skills, with visual programming proving particularly motivating for female participants. These findings suggest that integrating STEM Kits with block-based programming can enhance computational thinking across genders and promote greater educational equity. Early exposure to these tools in university curricula is recommended to foster technical and scientific competencies and support gender inclusion in STEM education.

Keywords: computational thinking; gender equity; STEM education; visual programming; educational technology; engineering students

Section II

Contributions in: Creativity, Graduate Attributes, Manufacturing, Students' Engagement, Well-Being, Sketching, Active Learning, Social Cognitions, Self-Efficacy, Marketspaces, Students Assets, Process Safety, Problem Solving, Entrepreneurship, Assessment, Biomedical Engineering, Laboratory Safety, After Class Learning, Students' Satisfaction

Shannon M. Clancy, Shanna R. Daly and Colleen M. Seifert

Engineering education and training often focus on convergent thinking processes to guide decisions using formal and analytical methods. However, divergent thinking processes such as considering multiple options, are necessary before making a choice, providing opportunities for improved approaches and innovative outcomes. Divergent thinking promotes flexibility through considering broader and more diverse perspectives and navigating ambiguity present in real world engineering projects. However, while divergent thinking is critical to engineering work, it receives little emphasis and understanding. Thus, our study focused on identifying facilitators and barriers to students' divergent thinking in project experiences. We interviewed 20 mechanical engineering undergraduate and high school students about their divergent exploration during extended engineering projects. We used two different narrative inquiry methods to understand intersecting barriers and facilitators and provide in-depth examples of participants' perspectives navigating divergent thinking in specific engineering contexts and structures. Our findings identify various crucial factors, notably *project structure and requirements, organizational culture*, and *mentorship direction* (authority and guidance) as impediments and promoters of divergent thinking in engineering student projects. The findings inform pedagogical approaches and engineering education structures and environments to foster divergent thought, challenging what engineering work can include, how engineering work is conducted, and who participates in engineering.

Keywords: divergent thinking; creativity and innovation; barriers and facilitators; organizational structures and environments; engineering culture; engineering education

Arthur James Swart and Pierre Eduard Hertzog

Graduate attributes (GA) have been integrated into curricula at many universities around the globe, as higher educational institutions seek to make their graduates more employable. The International Engineering Alliance released VERSION 4 of a document listing 11 GA that engineering students need to demonstrate through their educational career. Equally important are learning outcomes (LO) that clearly indicate what is expected of students to demonstrate or achieve during a specific module or course. The purpose of this article is to present a technique that may be used to develop a word code file that enables one to link LO to GA. This code can then be used with AI or quantitative data analysis programs to provide a network map of the GA, thereby providing evidence of their integration within a curriculum. A mixed-methods approach is used focusing on a 280-credit Diploma in Electrical Engineering. The technique focuses on pre-processing the LO of the curriculum, creating a frequency count of the words used, and drawing on the definitions of the attributes to create a word code file. This file lists the 11 GA where key verbs or nouns are associated with each attribute. Applying this file to all the LO in an Electrical Engineering curriculum revealed how the attributes are integrated, with Problem analysis being the dominant attribute. It is hoped that this word code file may be used with other engineering curricula to obtain a clearer picture on the integration of GA.

Keywords: IEA; integration; KH Coder; ChatGPT

Biljana Cvetic, Milos Danilovic and Miljana Lukovic

Material Requirements Planning (MRP) is a commonly used method and system for production and procurement planning in manufacturing companies. In practice, MRP functionalities are provided as a core module of the Enterprise Resource Planning (ERP) systems, but can also be offered via software tools. As MRP competencies are vital for several engineering roles, their attainment is one of the operations management and industrial engineering education goals. Accordingly, in this work, the possibilities and effectiveness of a new online MRP learning tool are assessed. The new MRP module from web-based OPR-MAN software was chosen following a customized selection procedure aiming to identify the most suitable MRP educational software for the Computer Integrated Manufacturing (CIM) course at the Faculty of Organizational Sciences, the University of Belgrade. The chosen module was subsequently applied when teaching several generations of students attending the CIM course. Its effectiveness was assessed both quantitatively (considering students' test scores as a measure of individual performance) and qualitatively (using online questionnaire probing students' overall satisfaction with this tool). A total of 145 students participated in the evaluation and the results showed that students acquired advanced MRP competencies and were very satisfied with the use of this new online tool for learning MRP.

Keywords: Material Requirements Planning; MRP; educational software; OPR-MAN, POM-QM for Windows; evaluation

Katarina Petrović, Dragan LJ. Bjelica, Marko Mihić, Dejana Pavlović, Duško Bodroža, Mihajlo Djukić, Elena Jovičić, and Zorica Mitrović

Higher education institutions are committed to continuous enhancement of educational programs to ensure alignment with student needs and expectations. Nevertheless, there remains an insufficient grasp of students' perceptions of well-being dimensions, limiting institutions' ability to create responsible supportive environments. The study aims to offer deeper understanding of engineering student's perspectives on the relevance and impact of key components influencing their well-being. Based on literature review insights and the identified research gap, the OECD Better Life Index dimensions were applied at the micro-level to examine students' perceptions. The study included 276 first-year undergraduate engineering students enrolled at the Faculty of Organizational Sciences. Descriptive statistics were used to assess the perceived importance of individual dimensions, while the Mann-Whitney test identified potential gender related differences and correlation analysis explored relationships among dimensions. The analysis highlighted that personal and professional advancement are seen as having significant importance, while there is high unawareness on importance of civic engagement and social responsibility. The findings highlight both what students seek and the areas where higher education institutions need to respond by helping students understand the importance of less prioritized dimensions and offering them engaging opportunities. This study makes a meaningful contribution by clarifying how young people perceive various well-being dimensions and aligning these insights with strategic approaches that higher education institutions can implement, therefore offering practical guidance and recommendation for fostering higher student engagement.

Keywords: well-being; student perception; engineering student's engagement; OECD; Better Life Index; responsible education

Prior literature has supported the use of sketching as a beneficial skill and communication tool for engineering students. Specifically in the mechanical engineering curriculum, sketching can be of vital importance in engineering design activities and can promote spatial visualization skills. Besides its benefits, in many universities, sketching is not part of the regular engineering curriculum, indicating the need to conduct studies to examine its importance and impact on engineering students' training. We hypothesize that sketching, with its ability to enhance students' visualization skills and critical thinking, will be able to minimize students' intellectual inhibition (i.e., a state where students count sketching as not valuable for their field). Thus, the purpose of this study is to understand students' perspectives on sketching if introduced in their mechanical engineering curriculum. Using a multi-method approach, we collected the data from 130 students belonging to three different universities in the United States. Students participated in surveys to share their perspectives towards sketching and their prior experiences; students also answered the open-ended questions to describe why they believed sketching should be taught to mechanical engineers. We used self-determination theory as an analytical lens to explain our findings. The quantitative data were analyzed using the Chi-Square test of independence, and the qualitative data were analyzed using an open coding mechanism. The results indicate that students showed a positive attitude towards sketching regardless of their demographic background and prior sketching experience. Also, students significantly advocated for including sketching training in the curriculum. Students indicated sketching as an engineering competency-enhancing and autonomy-enhancing skill that promotes relatedness within engineering. The results of this study are novel and help to share the importance of sketching instruction to the engineering education community, including educators, curriculum developers, and pedagogical experts, leading to the integration of sketching training in engineering.

Keywords: sketching; self-determination theory; mechanical engineering; students' perspectives

Scholarship in engineering education has emphasized the use of instructional activities based on active learning approaches to improve student engagement and performance. While the literature in engineering education generally supports the effectiveness of active learning, its effectiveness in computer science has yielded mixed results. Most of these mixed results are attributed to the design and implementation of instructional activities. It is thus important to capture students' perceptions of the design and the outcomes of these activities. In this study, following the Interactive, Constructive, Active (also known as Attentive), and Passive (ICAP) framework, we examined students' perceptions (N = 88) of instructional activities and their engagement in an undergraduate computer science course (i.e., systems analysis and design). Specifically, we examined the relationship between student perceptions of instructional activities, performance, and engagement. We also investigated the combined impact of instructional activities and engagement on performance. The findings showed that instructional activities statistically significantly predicted engagement. Contrary to earlier studies on the ICAP framework and in alignment with literature on computer science, there was no statistically significant impact of instructional activities and engagement on student performance. Moreover, no statistically significant interaction effect between instructional activities and engagement was observed on student performance. The results offer novel insights into the subjective nature of instructional activities and students' preferences for these activities. The paper situates the findings within the context of previous literature. Implications and considerations for educators are discussed for the design and implementation of active learning activities.

Keywords: active learning; ICAP framework; engagement; student perceptions; performance

Improved performance, persistence, and success in STEM fields such as engineering can be achieved through enhancing social cognitions (self-efficacy, outcome expectations, and persistence intentions). These cognitions are malleable and may be improved through instructional strategies that are tailored to feed into social cognitions. A faculty learning community (FLC) may be an effective approach to educate faculty on instructional strategies targeted toward these social cognitions. This study sought to determine if improvements in teaching practices targeted toward social cognitions and implemented through a faculty learning community yielded improvements in student social cognitions. Faculty were instructed in social cognitive teaching practices and implemented them in their classes to determine changes in student social cognitions. There was no significant change or a significant decrease in scores on several social cognitions. Instructors with higher fidelities were able to reverse significant decreases on some self-efficacy measures with treatment. Furthermore, students' final grades were positively moderately correlated with the change in social cognitions, with the correlation stronger in the post survey than in the pre survey. It is possible that with improved fidelity of implementation as well as consistent implementation across multiple courses, the use of FLCs to improve engineering students' social cognitions may have greater success.

Keywords: social cognitions; self-efficacy; faculty learning community; instructional strategies; engineering education

The maker movement has led to an increase in university makerspaces, where a low barrier-to-entry enables students of all experience levels to engage with technology such as additive manufacturing (AM). However, the range of student skills can result in frequent build failures, which in turn contribute to increased maintenance or student frustration. To identify key causes behind failed AM builds in a student-focused makerspace, this paper outlines how a crowdsourcing-based data collection tool was formulated that automatically extracts design and print information through printer files and correlates this information with student evaluations of their part's build quality, thus allowing for common sources of failure within the space to be readily identified. 77 unique makerspace builds, made up of 228 individual parts, were collected and analyzed for relationships between build quality and parameters selected in the slicing process. Through this approach, student-focused makerspaces may be able to leverage the significant amount of design and manufacturing information being processed through the space to better support student efforts, thus reducing the potential for frustration and improve learning outcomes.

Keywords: crowdsourcing; additive manufacturing; informal learning; makerspaces

University makerspaces are a growing resource in on-campus facilities, commonly in STEM buildings, that house a variety of tools and resources for making and crafting. Often, students in STEM majors take on leadership roles in makerspaces, positioning them as the brokers of culture who set the tone for the makerspace. Students who use makerspaces can gain a variety of technical and professional skills in makerspaces, but women, Students of Color, and disabled students are commonly excluded from the space. The culture of makerspaces, especially of what cultural resources are valued, can be explored through the experiences of student staff members. Through interviews with student staff at two university makerspaces at Hispanic Serving Institutions (HSIs), this paper explores the research question *How does existing makerspace culture support student assets through the lens of Community Cultural Wealth?* In these eleven interviews, the student staff recognized forms of Community Cultural Wealth (CCW). Student staff most notably recognize and value social capital, alongside other forms of CCW. Social capital is in line with the documented experiences of student staff in makerspaces as the brokers of community. These findings show the opportunities to support students', especially Students of Color, by continuing to value these forms of CCW in makerspaces.

Keywords: makerspaces; Community Cultural Wealth; student assets

Sherri Youssef, Amanda Singer Nault, Cayla Ritz, Brittany Butler-Morton, Emily Dringenberg, Cheryl A. Bodnar and Elif Eda Miskioğlu

Engineers are socialized to believe they make rational judgments by objectively using logic. This belief is at odds with engineering practice, where judgments are typically complex and difficult to quantify. Researchers have established that what individuals believe they will do and how they actually behave is often not the same. This gap can be particularly problematic for engineers where the judgments they make have significant implications not only for their organizations but the broader community and environment. Increasing engineers' awareness of gaps between their beliefs and behavior is important to help generate awareness of any discrepancies that may need to be mitigated in future judgments. We explored how engineering practitioners and students reacted when made aware of gaps between how they thought they would behave (espoused beliefs) and how they behaved when making judgments in the context of a process safety game (simulated gameplay behavior). Specifically, we answer the following research question: How do engineering practitioners and students react when presented with gaps between their espoused beliefs and simulated gameplay behavior? We conducted and analyzed qualitative, semi-structured interviews during which participants (13 industry practitioners and 12 engineering students) were asked to respond to the gaps that previous analysis had identified between their espoused beliefs and simulated gameplay behaviors. We used inductive coding strategies to develop themes characterizing their ways of reacting and then used pairwise comparisons to compare the reactions of practitioners and students. When presented with a gap in their espoused beliefs and simulated gameplay behaviors, engineering practitioners and students reacted in both similar and different ways—they equally blamed elements of the game for causing these gaps, citing boundaries posed by the game as limiting their desired behavior. In addition, practitioners tended to invoke their prior experiences and describe the parallels between the game and reality, but were less likely to engage in reflection when presented gaps. Meanwhile, students tended to engage in reflection, discussing changes to their future behaviors and beliefs. Students' justification of their gaps also referenced a desire to "win" the game which showcased the influence of game-based elements, such as scoring metrics, had on their behavior. These findings suggest that students are more likely to engage in reflective thinking, highlighting tailored interventions that raise awareness of belief-behavior gaps for students transitioning into professional roles.

Keywords: engineering profession; process safety; qualitative; senior; reactions

Yusuf Kaplan, Hasan Bakirci and Yilmaz Kara

This research investigates the effect of engineering design-based science teaching (EDBST) on middle school students' creative problem-solving, entrepreneurship skills, and views on engineering-based teaching. A mixed design approach was adopted for this research, which combines quantitative and qualitative research designs. Twenty students in the experimental group received training designed through the EDBST, while the 20 students in the control group received training using the 5E learning model. The Creative Problem-Solving Attributes Inventory, Science-Based Entrepreneurship Scale, and semi-structured interview form were used as data collection tools. As a result, EDBST positively affected middle school students' creative problem-solving and entrepreneurship skill levels. In addition, students reported feeling more creative and happier at the end of the teaching process, and that positive changes in their perception of engineering were evident. Thus, EDBST practices should be incorporated into strategies to develop the creative, problem-solving, and entrepreneurial skills of future individuals.

Keywords: creative problem solving; engineering design; entrepreneurship; middle school; science teaching

Matthew W. Ohland, Misty L. Loughry and David J. Woehr

Student engagement is critical for learning, persistence, retention, and other outcomes that matter to students and universities, yet there is little agreement about how the concept is defined and measured. The literature is unclear on whether aspects of burnout reflect low engagement or burnout is a separate construct. This construct ambiguity makes it difficult to develop a coherent body of scholarship about how pedagogical and institutional choices impact student engagement and how student engagement affects important student and institutional outcomes. The primary goal of this paper is the development and evaluation of a new comprehensive measure of student engagement drawing from the literatures on personal, student, school and job engagement and burnout. Toward this end, we conducted three studies. Study 1 examines the factor structure that emerges from a comprehensive set of items from published instruments in the engagement and burnout literatures. Results indicate that student engagement is comprised of six dimensions: *Enthusiasm, Exhaustion, Effort, Social Interaction, Resilience*, and *Focus*. Study 2 focuses on the development and initial psychometric evaluation of a novel measure of student engagement based on the six factors. Study 3 provides additional psychometric evaluation of the new measure of student engagement. Together, results across the three studies provide considerable support for a 24-item (four items per dimension) measure of student engagement with a consistent stem that can be modified to customize the referent of the questions. We provide evidence for reliability and validity of the 24-item scale as well as each of the six subscales.

Keywords: student engagement; job engagement; burnout; scale development

Ahmad O. Alokaily, Suhail S. Alshahrani, Ahmed A. Aldohbeyb, Soliman A. Alhudaithy, Abdulaziz S. Fakhouri, Mohammad K. Alsenaide and Abdulelah S. Alrebaish

Laboratory safety is a critical component of biomedical engineering (BME) education due to the interdisciplinary nature of the field and the associated chemical and electrical hazards. Despite its importance, limited data exist on the safety awareness of BME students in Saudi Arabia. To evaluate the knowledge, attitudes, and cognitive risk perceptions of undergraduate BME students regarding laboratory safety. A cross-sectional study was conducted among 129 undergraduate BME students from various Saudi universities using a 39-item questionnaire that covered demographics, safety knowledge, attitudes, and risk perception. Data were analyzed using nonparametric tests due to non-normal distribution. The mean knowledge score was 8.4 ± 2.4 (out of 12), with 65.1% demonstrating high knowledge levels. Knowledge significantly increased with academic level, while gender, training, and access to safety manuals showed no effect. Attitudes toward safety were mainly positive (25.0 ± 4.0 out of 35); however, concerns were raised about the availability of personal protective equipment and insufficiently emphasized safety policies. Risk perception was context-dependent: students perceived significantly higher risk in non-compliance scenarios (19.4 ± 4.0 out of 25) compared to compliant ones (12.4 ± 3.5 out of 25). Although students exhibited satisfactory knowledge and attitudes, critical gaps remain in chemical hazard awareness and emergency preparedness. Integrating structured, hands-on safety training into biomedical engineering curricula is crucial for advancing practical readiness and fostering a sustainable safety culture among students and academic institutions.

Keywords: biomedical engineering education; laboratory safety; sustainable laboratory practices; risk perception; safety culture; sustainable development in higher education