

# The International Journal of Engineering Education

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**Gaetano Cascini—Politecnico di Milano, Dipartimento di Meccanica**  
**Noel Leon Rovira—ITESM-Campus Monterrey, Centro de Diseño**  
**e Innovación de Productos**

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Computer technologies are widely used to facilitate teaching of creative problem solving and to help engineers in their day-to-day work. To ensure effective utilisation in engineering practice, it is imperative to better understand the problem solving process itself. This research used an exploratory approach (Grounded Theory) to understand the complexities of engineering problem solving. Interview data from 22 engineers ranging from novice to experts, including 15 male and 7 female engineers were discussed. The participants believed that problem identification is the most crucial stage in good problem solving. ‘Options’ were identified as deterrents to long-term development of problem solving ability. It was established that it is necessary to boost self-efficacy of young engineers and make them willing to face challenges despite ‘options’. Participants also suggested that conscious understanding and awareness of their own problem solving strategy is vital to the development of their problem solving skills. Findings from this paper provide new insights on how engineers develop their problem solving skills and can be used to improve existing theories on problem solving. These findings have implications on general educational strategy, as well as the development and implementation of computer technology for engineering problem solving.

**Keywords:** problem solving; problem identification; self-efficacy; long-life learning; transferability

Marina Carulli, Monica Bordegoni and Umberto Cugini	291–303	An Integrated Framework to Support Design & Engineering Education
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The current particular critical moment for the Western industry, and the introduction of information technologies have profoundly changed the product development process. One of the most important modifications occurred is the integration of the two traditional fields of product design and product engineering into the new concept of industrial Design & Engineering. The consequent shift and the extension of the designer’s area of expertise concerning the product development process have led to amplify his typical knowledge: both more and more technical knowledge, and also knowledge more focused on conceptual issues and creativity. This trend is fostered by the intensive use of computer systems and also by various Design & Engineering courses, where it has been possible to experimentally observe the difficulty for students to learn the necessary body of knowledge and to manage a wider product development process. However, the multidisciplinary approach to the product development process and to the related education issues are still based on tools and methods developed for a specific kind of user, or usually used in an unarranged way. The research presented in this paper aims at defining the guidelines for developing an integrated framework to support the Design & Engineering education and the multidisciplinary design process based on a structured integration of knowledge and tools currently used by the two main areas of reference. The paper presents the guidelines for the integrated framework and the experimental activities used for the framework validation. These activities have allowed the authors to check the framework usability during team design activities and also to verify its effectiveness in improving students’ learning capabilities. Some elements derived from the analysis of the experimental data demonstrate that both students and professional designers can use the framework to assist them throughout the design process and that the knowledge learning related to the project is fostered.

**Keywords:** multidisciplinary design; design & engineering; design process; design education

Denis Cavallucci and David Oget	304–317	On the Efficiency of Teaching TRIZ: Experiences in a French Engineering School
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Our industry is currently undergoing a transformation that is guiding it from the quality era to that of innovation. This transformation necessarily involves changing design practices, the foundations of which currently rest on an optimization mentality. An innovation oriented approach would require that the bases of the design action contain other rules of invention where creativity and problem solving would have priority. In order to address these requirements, some teaching institutions have initially resorted to teaching creativity methods by simply stimulating the ideation phases of standard design processes. Having reached the limit of what creativity methods could contribute, TRIZ appears as a likely alternative to such methods by providing greater structure and more results. However, the first experiments in teaching TRIZ rapidly revealed an incompatibility between the time needed for effectively using it and the time generally allotted for teaching a new method. This article presents the results of an experiment in introducing new TRIZ software and the way in which it was implemented in engineering students’ coursework at INSA-Strasbourg over the past three years. These results lead us to state that the use of software improves quality in the TRIZ teaching process, especially with regard to the number of skills dealt with and acquired by engineering students in project situations.

**Keywords:** inventive design; TRIZ; innovation; teaching skills

Niccolò Becattini, Yuri Borgianni, Gaetano Cascini and Federico Rotini	318–333	A TRIZ-based CAI Framework to guide Engineering Students towards a Broad-spectrum Investigation of Inventive Technical Problems
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Nowadays, a growing consensus is attributed to conceptual design in the perspective of developing effective and successful products; as a consequence, major efforts should be dedicated within the Computer-Aided Innovation field to correctly support this

task. A particular line of evolution of these systems concern computer coaches, i.e. software applications capable to assist users along each step of design activities. In such perspective the authors have developed a dialogue-based system supporting a natural language questioning procedure to investigate technical problems through TRIZ way of thinking. An emerging deficiency of its first version concerns limited capabilities in providing a broad screening of the issues and features relevant within the encountered inventive problems. The integration of a further analysis module supporting the logic of the TRIZ System Operator has allowed the individuation of effective resources for breaking technical conflicts inherent to the investigated systems or formalizing contradictions in TRIZ terms. The paper provides further support about the need of developing broad thinking skills in engineering education. The new generation of Computer-Aided systems is extending its scope, by supporting the user already from the early design stages, where creativity and cognitive processes are of paramount importance. In such context, the authors have developed a natural language dialogue-based framework capable to coach designers in investigating non-routine technical problems through a TRIZ way of thinking. The first version of the questioning procedure has showed limitations in terms of the capability to widen the designer's perspective, resulting in the overlooking of aspects relevant for the problem. The new version of the dialogue-based system integrates a further analysis module, here presented, supporting the logic of the TRIZ System Operator. New tests demonstrate that the modification allows to improve the quality of the analyses, especially in terms of the identification of features to be advantageously redesigned in order to solve the addressed problems.

**Keywords:** computer aided innovation; dialogue-based system; broad-spectrum investigation; inventive problem analysis; TRIZ

**Valentino Birolini, Caterina Rizzi and Davide Russo** 334–345 Teaching Students to Structure Engineering Problems with CAI Tools

The importance of methodologies and computer-aided tools for problem structuring and solving has been demonstrated by various research activities since the 1970s. The need for systematizing the first phase of problem solving activity has led the authors to the development of a dedicated procedure for problem reformulation and the implementation of a dedicated software package, named BOB-UP®. It aims at driving the user to reformulate the initial problem using a dialogue-based system hiding an accurate cause-effect analysis. BOB-UP® provides three tools (Ill-Balls diagram, Fight diagram, and a linguistic composer) that guide step-by-step the user to the right problem formulation. This paper presents the experimentation of such CAI tool within two courses at the University of Bergamo. The first is a compulsory course for the master degree in Mechanical Engineering, while the latter is an elective course for the master degree in Mechanical Engineering and Management Engineering. The experimentation has been carried out with 56 students sub-divided into three groups according to their competences on problem structuring and solving and technical background. We considered five problems related to industrial applications coming from different technological domains to demonstrate the independence of the results from the specific industrial area. Finally, results are discussed presenting advantages and drawbacks. They have been evaluated according to specific criteria to evaluate its usability and efficacy; in addition, students were asked to fill a questionnaire to comprehend the perception they have on BOB-UP® usefulness and potential.

**Keywords:** engineering education; problem structuring; cause-effect analysis; CAI tools; TRIZ; BOB-UP®

**Iouri Belski, James Baglin and Jennifer Harlim** 346–354 Teaching TRIZ at University: A Longitudinal Study

This paper discusses the outcomes of the course on Theory of Inventive Problem Solving (TRIZ unit) delivered at the Royal Melbourne Institute of Technology (RMIT) over the last five years. It analyses the results of numerous surveys on students' problem skills and compares the impact of the TRIZ unit with the impact of a typical engineering unit on students' problem solving abilities. The results presented in this paper suggest that the enrichment approach is superior to the infusion approach for teaching engineering problem solving. The TRIZ unit was also found to enhance students' problem solving self-efficacy significantly more than the four years of an engineering degree. It is concluded, that the most likely reasons for a success of the TRIZ unit can be explained based on the information-processing theories of problem solving: it explicitly teaches tools for problem representation as well as formal problem solving heuristics.

**Keywords:** Keywords: problem solving skills; TRIZ; self-efficacy

**Marco A. de Carvalho** 355–364 IDEATRIZ—A Methodology for New Product Ideation

Organizations seeking to be innovative face many dilemmas. The main one is that, though it is necessary to innovate, innovation is a highly risky activity. The focus of this paper is on the root of product innovation, which is new product ideation. The prevailing literature in this area tends to put emphasis on the external source for new product ideas—namely, the market. The fact that the external source cannot lead to truly original product ideas seems to be ignored. In this paper, the IDEATRIZ methodology is presented. This is a different approach to new product ideation, based on the use of the internal source—an organization's own resources. A background for this approach is provided, as well as a description of the methodology itself and activities conducted regarding its validation—tests performed during its development and three cases where the methodology was used for new product ideation in real projects. Results show that the methodology is effective, with a higher output of creative (both original and useful ideas) than other ideation methods and methodologies. Finally, planned activities regarding the computerization of IDEATRIZ are discussed.

**Keywords:** product development management; product innovation; new product ideation; Computer Aided Ideation; TRIZ (Theory of Inventive Problem Solving).

**Shi-Jer Lou, Chih-Chao Chung, Wei-Yuan Dzan, Kuo-Hung Tseng and Ru-Chu Shih** 365–379 Effect of Using TRIZ Creative Learning to Build a Pneumatic Propeller Ship while Applying STEM Knowledge

This study aims to explore the effects of the Theory of Inventive Problem Solving (TRIZ) creative learning method to build the pneumatic propeller ship while applying STEM (science, technology, engineering, and mathematics) knowledge among Taiwanese female high school students. The subjects were 70 female students from a high school in Pingtung, Taiwan. An online platform was created and served as the TRIZ creative learning environment for the pneumatic propeller ship project. The students were provided with opportunities to discuss, share, and integrate their knowledge. Questionnaires and focus group interviews were conducted for data collection and analysis. The findings of this study revealed that (1) the STEM & TRIZ integrated instruction model can systematically promote STEM knowledge integration and application; (2) applying TRIZ creative learning to STEM knowledge show positively influences on students' learning; (3) the STEM & TRIZ integrated instruction model can enhance students' learning attitudes and interests; (4) the STEM & TRIZ integrated instruction model can enhance students' creativity and efficiency and cultivate students' innovative skills; and (5) applying TRIZ creative learning to STEM knowledge positively influences the students' creative learning.

**Keywords:** TRIZ creative learning; STEM knowledge; female high school students

**Carlos Rivera-Solorio, Alejandro J. García-Cuéllar and Abiud Flores** 380–387 Design and Construction of a Boat Powered by Solar Energy with the Aid of Computational Tools

The senior design project in engineering curricula is undoubtedly one of the prime opportunities for future engineers to synthesize knowledge acquired during their college education. We adopt the perspective that product development is an engineering and social

activity aimed to satisfy human needs eliminating the negative environmental impact. This definition is delivered in our students through design experiences aimed under a project-oriented design course. This article seeks to give an overview of this project and to summarize the experience of the past two years that has led to improvement in the designing experiences in the capstone project. The project actively uses CFD (Computational Fluid Dynamics), CAM (Computer Aided Manufacturing), FEM (Finite Element Method) and CAD (Computer Aided Design) software as tools for enhancing the innovative capacity of senior year engineering students. Seniors working collaboratively were asked to design a solar-powered boat while taking hydrodynamic, energy and economic factors into consideration. We show how computational tools accelerate decision making processes in design while suggesting promising directions for the students to follow. All this is done while adhering to the fundamental principles in engineering that will lead to a feasible solution. Student creativity was channeled appropriately through CFD, FEM, CAM and CAD tools and new ideas were rigorously and rapidly tested at an early stage in the project allowing for a wide exploration of ideas and concepts. An important result of this capstone activity is the realization by the students of the importance of specialized engineering software in achieving a successful design. The objective of this paper is to present and discuss results obtained while observing students work with computer tools as a way to enhance their creativity in the context of developing their senior design project.

**Keywords:** innovation; prototype; computational tools; design; solar-powered boat

## Section II

### Contributions in: Service Learning, Gender Issues, Non-Technical Competencies, Professional Communicating, Project-Based Learning, Engineering Design, Design-Based Learning, Online Teaching, Blended Learning, Assessment, Modeling, Pneumatic Systems

**Holly M. Matusovich, William Oakes  
and Carla B. Zoltowski**

388–402 Why Women Choose Service-Learning: Seeking and Finding Engineering-Related Experiences

As a field, engineering remains challenged with regard to gender parity and ethnic diversity despite efforts over the last 20 years aimed at closing such gaps. Although research and curricular reform efforts have advanced our understanding of what works to attract women to engineering, we still know little from the student perspective as to why some practices are successful in attracting and retaining women. It is not enough to know what works, but we must also know why some practices work in order to create lasting change and reach diversity goals. Our study begins addressing this why question by qualitatively examining eight women participants' choices to enroll in a service-learning course (Engineering Projects in Community Service (EPICS)) that has been successful in attracting women over 16 years. Our results show that our participants choose EPICS as a way to gain experience doing engineering; that EPICS provides the benefit of contextualized learning with resulting impacts within EPICS and in other classes, and that EPICS positively impacts commitment to engineering. Interpreting our results, we argue that women are seeking ways to gain engineering experience in a setting that is comfortable to them, such as EPICS. The context of the experience and ability to help others is important, but secondary to gaining engineering experience.

**Keywords:** service-learning; self-efficacy; gender

**Elisabeth Larsson, Stefan Pålsson,  
Jarmo Rantakokko, Lina von Sydow  
and Michael Thuné**

403–414 Gender-Aware Course Reform in Scientific Computing

A holistic approach was used to thoroughly redesign courses in Scientific Computing at Uppsala University. The objectives were two-fold: to improve the learning outcome for students in general and to make the courses more appealing to women students in particular. The redesigned courses include a combination of learning activities motivated by previous research on preferences of women students regarding learning environments and educational approaches. Moreover, particular care was taken to design the courses according to the principles of constructive alignment. This was achieved by structuring the course content into thematic modules, where each module was organized into different learning activities with several cycles of action, observation and reflection. Indications that the resulting course design fulfils the objectives stated above are, for example: that the students get a clearer and more coherent view of the subject; that they consider the courses to be well-structured with well-connected activities; and that the student-student and student-teacher interactions are increased. The new course structure is clearly appreciated, especially by female students, and considered to be important for the learning process. The conclusions are supported by qualitative as well as quantitative evidence.

**Keywords:** scientific computing; gender; holistic; constructive alignment; action research

**Brenda M. Capobianco and Irene B. Mena** 415–425 Longitudinal Profiles of Children's Conceptions of an Engineer

This study examines elementary school (grades 1–5) children's conceptions of an engineer as they progress from one year to the next over a three-year period. Data were gathered from three distinct cohorts of students progressing from grades 1 through 3, 2 through 4, and 3 through 5. Using the Draw-An-Engineer Test and semi-structured interviews, we explore children's conceptions before and after they engaged in engineering design-based lessons and furthermore, demonstrate how conceptual change occurred among distinct cohorts of children. Data were analyzed using grounded theory. Results indicated that children were more likely to invoke more fragmented conceptions at younger ages (grades 1 and 2) and more diverse and accurate conceptions as they progressed from grades 3 to 4 to 5. Retention of more accurate conceptions occurred among children at an older age. Consideration must be given to the development of high quality engineering design-based instructional materials and curricular resources that can capture children's naive ideas and furthermore, promote students' abilities to develop more meaningful, accurate understandings over time.

**Keywords:** engineering; elementary; conceptions; case study

**Richard LeBoeuf, Matías Pizarro and  
Ricardo Espinoza**

426–438 Identification of Non-Technical Competency Gaps of Engineering Graduates in Chile

A study was performed to identify the non-technical competencies needed by engineering graduates in Chile. A list of abilities and knowledge attributes were derived from similar studies and the expectations expressed by professional organizations. Input was received from managers of 75 different companies across a broad range of industries and sizes and 116 engineering graduates regarding the importance and preparation for 57 abilities and knowledge attributes in 10 categories. Each competency was given a priority based on one of three criteria: 50% or more of managers reporting it to be of the highest level of importance, an average rating greater than a cutoff, and a weighted measure of priority incorporating the importance and gap between graduate

preparation and needs. The results suggest that, to managers in Chile, the most important non-technical competencies are in the areas of project control, ethics, communications, teamwork, innovation and budgeting. The competencies identified as important were similar to those seen in studies in other countries, but with a greater emphasis on ethics and innovation and less emphasis on quality and customer focus. A method for prioritizing the important competencies was also presented. Many initiatives were proposed to improve specific non-technical competencies that graduates need for competing in the Chilean job market. This paper presents the methodology, the findings, the comparisons with results from similar studies in other countries, and the strategies developed as a result of the findings.

**Keywords:** engineering education; non-technical competencies; soft skills; management

**Tharwat El-Sakran, David Prescott and Mujo Mesanovic** 439–449 Contextualizing Teamwork in a Professional Communication Course for Engineering Students

The paper outlines evidence from studies concerning the importance of professional communication for engineering students. This is followed by description of syllabus change at the American University of Sharjah to address a perceived need for professional communication skills. The paper then reports the procedures employed to contextualize these skills through engineering multidisciplinary projects (EMDPs). Discussion of the use of the Belbin Get-Set Self Perception Inventory (SPI) to develop team-role behavior is considered. The paper outlines an investigation of the perception that student understanding of team-role behavior is positively influenced by self-awareness and the contextualized work undertaken in EMDPs. The data used in this investigation were the preference scores obtained from two administrations of the Belbin Get-Set Self Perception Inventory (SPI) with three cohorts of students ( $n = 56$ ), at the commencement and completion of Spring Semester, 2011. Values from the two administrations of the Belbin SPI were tested to establish whether there was statistically significant improvement. Findings indicate positive change in students' understandings of the significance of team-role behavior. At ten per cent (10%) of significance strong evidence of significant improvement in four categories was recorded for individual results and in three categories for team results.

**Keywords:** engineering multidisciplinary projects; professional communication; team role behavior; team-building; collaborative

**Steven C. Zemke and Diane L. Zemke** 450–458 Cognitive Hindrances to Learning Mechanical Design

Engineering design is commonly taught by pacing student teams through design projects while teaching open-ended problem solving methods. This strategy addresses curricular content, but may not fully support students' cognitive learning needs in design. The purpose of this study was to explore the cognitive hindrances mechanical design students experience while learning design. A class of 29 students in a junior mechanical design course provided learning journal reflections during the semester on teamwork and learning design. These data on learning design were coded to surface cognitive hindrances. Common cognitive hindrances included a lack of design language, an unstocked repertoire, the unreliability of the imagination, and fixation throughout the design cycle. Based on the nature of these hindrances, we offer implications for teaching design courses.

**Keywords:** design cognition; design education; engineering design; communication; imagination

**Oenardi Lawanto, Deborah Butler, Sylvie Cartier, Harry B. Santoso and Wade Goodridge** 459–475 Task Interpretation, Cognitive, and Metacognitive Strategies of Higher and Lower Performers in an Engineering Design Project: An Exploratory Study of College Freshmen

This paper examines the task interpretation and strategy use of higher- and lower-performing college freshmen while engaged in an engineering design project using a self-regulated learning (SRL) framework. Our goals were to consider how students' interpretation of task demands could be associated with their use of planning, cognitive, and monitoring/fix-up strategies, both as part of the design process and when managing their time, resources and teamwork. The main research question that guided the study was: In what ways did higher- vs. lower-performing students differ when engaged in an engineering design project? With regards to this question, we specifically explored how these two groups of students were similar or different in their: (1) task interpretation in relation to reported strategy use during the design process; and (2) task interpretation in relation to reported strategy use in project management. Seventy freshman engineering students enrolled in an introductory engineering design course at Utah State University were recruited for the study. From among that group, data from 20 higher- and 12 lower-performers were selected for analysis. Survey instruments and Web-based design journal entries were used to capture students' task interpretation, reported strategy use, including planning (PS), cognitive (CS), and monitoring/fix-up strategies (MF), and perceptions of important performance criteria (CR). Students' design performance was evaluated by the teacher. Descriptive and nonparametric statistics and graphical views were used to analyze student SRL profiles. Entries from students' design journals were coded using an SRL model and interpreted to triangulate and complement survey data to achieve deeper insight about SRL between the two groups. The findings suggested that both higher- and lower-performers were highly aware of important task requirements. However, higher-performing students had a greater awareness and reported greater use of monitoring and fix-up strategies associated with success in the design process. The higher-performing students also obtained higher scores on criteria for performance than lower-performing students, both in the design process and project management. Furthermore, journal writings revealed that higher performers were more thorough in identifying and describing design requirements and strategies for their projects than were the lower performers. This paper discusses the potential implication for design instruction in engineering college freshmen.

**Keywords:** cognitive strategies; college freshmen; engineering design; metacognition; self-regulated learning; task interpretation

**Andrés Díaz Lantada, Pilar Lafont Morgado, Juan Manuel Muñoz-Guijosa, José Luis Muñoz Sanz, Javier Echávarri Otero, Julio Muñoz García, Enrique Chacón Tanarro and Eduardo de la Guerra Ochoa** 476–490 Towards Successful Project-Based Teaching-Learning Experiences in Engineering Education

Problem- or project-based teaching-learning experiences (typically 'PBL' or 'PjBL') have enormous benefits but also certain limitations and difficulties that have been analysed in this work with the purpose of setting some standard guidelines that may help to enhance the results of this kind of teaching experience. A systematic, prioritised analysis of forty factors that influence this type of experience and affect the planning, organisation, development and assessment stages, has enabled us to find and formulate nine problems that we deem to be major ones and that are usually repeated, particularly in machine and product development related experiences in the area of Mechanical Engineering. Having selected these most typical problems, we have then established causal relationships by taking account of: the methodology involved, the available resources, the teachers in charge of the experience and the students taking part in it. This has helped us to find and put forward different solutions and to discuss their effects, keeping in mind our team's experience and the information from the studies carried out by teaching staff from other universities.

**Keywords:** project-based learning; improving teaching-learning processes; active learning; European Higher Education Area

**Sonia M. Gómez Puente, Michiel van Eijck and Wim Jochems** 491–503 Empirical Validation of Characteristics of Design-Based Learning in Higher Education

Design-based learning (DBL) is an educational approach in which students gather and process theoretical knowledge while working on the design of artifacts, systems, and innovative solutions in project settings. Whereas DBL has been employed in the practice of teaching science in secondary education, it has barely been defined, let alone investigated empirically, at the level of the higher education setting. The purpose of this study is to investigate empirically to what extent pre-defined DBL characteristics are present in an exemplary DBL practice in technical studies. As an exemplary case, we took four different engineering departments from a technical university in which DBL has been implemented as a central form of instruction. First, we conducted a survey to collect

teachers' and students' perceptions on whether DBL characteristics were, in fact, present in assignments and projects. Second, teaching materials and student products from three projects were analyzed qualitatively. We found that teachers and students recognized DBL characteristics as part of the instruction, albeit to a varied extent. We found considerable differences between departments, particularly in the characteristics of the projects, the role of the teacher, and the design elements. Analysis of DBL teaching materials and student products revealed that not all DBL characteristics are embedded in the projects over all departments. Implications for further research are discussed to optimize the instructional design of DBL environments.

**Keywords:** design-based learning; design thinking; engineering education; instructional design

**Can B. Aktaş and Yıldız Omurtag**

504–509 Online Teaching of Engineering Statistics: A Comparative Case Study

Various forms of online education are rapidly gaining ground in higher education institutions. Engineering programs lag behind in online education due to presumed difficulties associated with online lecturing of mathematics based courses. The goal of the study was to investigate whether there was a significant difference in the mean grades of students enrolled in two sections of a mathematics based Engineering Statistics course offered to undergraduate engineering students. While the course content covered in the two sections was identical, the medium of teaching was different in the two sections: one section carried out a traditional in-class lecture style whereas the other section employed a partially-online type of teaching. Thus, the intention was to explore if the two lecturing styles were equally effective with regard to student learning or if one was better than the other. Results from two sections were compared by using statistical methods and hypothesis tests. Students in the two sections resulted in similar mean values for course credits completed and cumulative grade point average, indicating that there was not a significant difference among student bodies in the two sections. While the dispersion of grades in the partially-online section was higher compared with the in-class lectured section, mean grades came out to be almost exactly the same, a result also supported by the hypothesis test conducted. Results indicate that there was not a significant difference in student grades, taken as indicative of their learning, when the two sections representing different styles of lecturing were compared. Results show promise with respect to the potential for online teaching of Engineering Statistics courses, as well as other mathematics based engineering courses.

**Keywords:** online education; blended education; engineering statistics; hypothesis test

**Lorenzo Moreno, Carina González,  
Evelio J. Gonzalez, Beatrice Popescu and  
Claudia O. L. Groenwald**

510–519 Teaching Computer Architecture using a Collaborative Approach:  
The SIENA Tool, Tutorial Sessions and Problem Solving

This paper presents a teaching–learning methodology that combines Blended Learning (BL) and Computer-Supported Learning (CSCL). We have created a tool called SIENA that assists students with self-learning. The SIENA tool uses conceptual maps and adaptive testing to guide the learning process of students working together in small groups. The tests, which include functions that are specifically suited to online collaborative work, use teaching–learning materials and questions that have been developed in collaboration with final-year students taking the subject Computer Architecture.

**Keywords:** higher education; blended learning; continuous assessment; collaborative learning; adaptive tests

**K. Jo Min, John Jackman and  
Doug Gemmill**

520–532 Assessment and Evaluation of Objectives and Outcomes for Continuous Improvement of an Industrial Engineering Program

In recent years, ABET accreditation has placed a heavy emphasis not only on the assessment of objectives and outcomes, but also on the evaluation of them and subsequent efforts for continuous improvement based on such an evaluation. Currently, a plethora of assessment tools and conceptual frameworks notwithstanding, there exists a relative paucity of documented efforts on the actual evaluation and subsequent continuous improvement. In this paper, we first concretely (1) show how such assessment and evaluation can be deliberately and systematically conducted in the context of an Industrial Engineering program. We then (2) show how the results of the objectives evaluation lead to the efforts towards continuous improvement through the student outcomes. Through (1) and (2), we enable others to specifically identify and prepare for the critical stages necessary to advance beyond a display of assessment tools and conceptual frameworks and to actually close the loop for a continuous improvement cycle.

**Keywords:** assessment; evaluation; objectives; outcomes; continuous improvement

**R. Payri, J. Javier López, F. J. Salvador  
and P. Martí-Aldaraví**

533–547 Development of a Methodology to Learn the Characteristics and Performances of Common Rail Injection Systems Based on Simulations with AMESim

An injector model built with the platform LMS Imagine.Lab AMESim has been introduced as a useful tool used in one of the practical lessons taught in the “Mixing formation and combustion systems in the Reciprocating Internal Combustion Engines” course. This course carries 6 ECTS and is a first year course in the second semester of the Master’s in “Reciprocating Internal Combustion Engines”. Using a standard model that has been previously implemented and validated, the students have to carry out an analysis of the injection process from the point of view of the operation of a modern solenoid-valve operated injector. The goal pursued in the lesson described here is, on the one hand, to help the students to understand how injectors work from the moment when they receive the current from the ECU of the engine up to when the fuel is delivered to the combustion chamber as a diesel spray. The different mechanisms involved will be analyzed by the students by exploring important internal variables, such as pressure variations, moving part displacement and, in overall terms, all the variables involved in the injection phenomenon. On the other hand, the students will be able to identify the critical parameters that play a major role, affecting the mass flow rate to a greater extent, by analyzing the response of the system under different geometrical configurations and different operating conditions. There is some evidence that the new teaching approach significantly improves the learning process when compared with the previous teaching methodology.

**Keywords:** injection modeling; diesel; students; workshop; AMESim

**J. Falcão Carneiro, M. R. Barbosa,  
P. Abreu and F. Freitas**

548–563 An Introductory Undergraduate Course on Fluid Power Systems

Fluid power systems play an essential role in modern industry, providing actuation means for a wide number of applications ranging from simple on-off movements, typically performed by pneumatic systems, up to complex servo hydraulic mechanisms used in industry. Despite this relevance, the studies of fluid power systems at an undergraduate level are often only focused on analytical analysis, creating a gap between the theory presented in the classroom and real world industrial problems. This paper presents an introductory graduate course on pneumatics and hydraulics where the more theoretical contents are complemented with unique educational laboratory experiments using ‘off-the-shelf’ industrial components and circuits. Sample lab assignments are described that emphasize the pedagogical value of this type of activities. The five different evaluation components used to assess students are presented and discussed. Finally, statistical results of the student’s opinion and grades on the course over the last 5 years are presented and commented.

**Keywords:** education; laboratory; pneumatic systems; hydraulic systems; mechatronics