

# The International Journal of Engineering Education

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### Part I

## Special Issue: Methodology for the study of PBL in Engineering Education

### Guest Editors:

**Anette Kolmos—UNESCO Chair in PBL in Engineering Education Aalborg University, Denmark**

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- Denis Bédard, Christelle Lison, Daniel Dalle and Noël Boutin** 511–522 Predictors of Student's Engagement and Persistence in an Innovative PBL Curriculum: Applications for Engineering Education
- The objective of this paper is to present the overall results of a study focusing on the engagement and persistence of undergraduate students in two PBL engineering curricula (Electrical Engineering and Computer Engineering) at the Université de Sherbrooke in Canada. We will also discuss the results in terms of applications for engineering education. There were 192 undergraduate engineering students who volunteered to participate in this study. First, they completed a questionnaire to measure the best predictors of students' engagement and persistence in their respective programs. Second, we met with 15 students who volunteered to participate in interviews. Results from the questionnaire show that the best predictor in both programs regarding students' engagement and persistence is the provided 'support,' which reduces stress. Results from the interviews reveal that the support most effective for students proves to be the stable learning environment (PBL tutoring sessions) as well as the scaffolding measures for managing time and organizing learning practices. Taking into consideration the results from both the questionnaire and the interviews, it appears essential to limit these risks by taking measures that will reduce stress factors and increase strong support.*
- Keywords:** problem-based learning; project-based learning; engagement; persistence; innovation; engineering education
- Benoit Galand, Benoît Raucant and Mariane Frenay** 523–534 Engineering Students' Self-regulation, Study Strategies, and Motivational Beliefs in Traditional and Problem-based Curricula
- Is problem-based learning (PBL) really effective? Evidence focusing on achievement provides mixed results, but a growing body of research indicates that PBL fosters students' academic engagement. However these studies are limited to the education of health professionals and do not include measures of implementation. The aim of the present study is to compare perceptions of the learning environment, motivational beliefs (self-efficacy and goal orientations), self-regulation strategies, study strategies, and satisfaction among engineering students before and after the shift from a lecture-based to a problem- and project-based (PBL) curriculum. The last cohort of students who attended the traditional curriculum and the first cohort of students who attended the new PBL curriculum participated to a questionnaire survey. Results of multivariate analyses show that PBL students perceived stronger academic support and weaker organizational structure. They also report more frequent use of adaptive self-regulation and deep processing strategies, less frequent use of surface processing strategies, lower satisfaction, higher attendance and longer study time. No differences were found for motivational beliefs and collaboration between students. Moreover, perceived learning environment mediates most of the observed differences between cohorts. Implications for attempts to improve student academic engagement are discussed.*
- Keywords:** higher education; problem-based learning; project-based learning; self-regulation; motivation; learning strategies
- Angela R. Bielefeldt, Kurtis G. Paterson, and Christopher W. Swan** 535–546 Measuring the Value Added from Service Learning in Project-Based Engineering Education
- There has been a recent surge in project based service learning (PBSL) in engineering education. PBSL covers a spectrum of community-based projects both locally and internationally. While PBSL experiences can be embedded within courses, in many cases these activities are facilitated by non-academic organizations, such as Engineers Without Borders. These PBSL activities have undergone increasing levels of assessment, driven in part by the outcomes assessment requirements for engineering program accreditation in the U.S., but also because of apparent positive impacts to student participants. These studies indicate that the knowledge and skills gained by the students are at least on par with gains from traditional project-based learning (PBL). Attention is also increasingly being focused on the potential impacts of PBSL on student attitudes and identity. It is in these areas that differences in the influence of PBL versus PBSL appear more profound, yet small numbers of student participants in various programs and a lack of coordinated assessment efforts limits the statistical significance of these results. This paper highlights possible methods to determine the added value of service-based learning especially when coupled to project-based engineering education. Examples of evidence in the analysis of PBSL versus PBL in engineering are provided to further examine the state of this field. Considerable research will be needed to fully understand how service learning is impacting the education of engineers.*
- Keywords:** project-based learning; service-learning; assessment; design; cultural competency; reflective essays

*Project Based and Problem Based Learning (PBL) has been widely utilised in engineering higher education. One of the many benefits from this innovative approach is enhanced critical thinking of students. However, there appears to be scope for developing how critical thinking can be integrated into PBL, to promote deep learning in a complex multi-disciplinary environment. This paper addresses this knowledge gap by presenting research in exploring PBL using an integrated critical thinking process model. The study was carried out on a cross-module multi-disciplinary group building design project, undertaken by second-year undergraduate students registered to the Environmental Building programme at University of Plymouth, UK. Although the students perceived critical thinking to be important to their projects, surface learning dominated the PBL process, particularly at the early stages of the project. To realise the full benefits from PBL, staff involved suggested that proper mechanisms should be provided to enable deeper learning. This requires the philosophy of critical thinking to be embedded in the design and implementation of the curricula, before and during the project. The process model of critical thinking developed provides such a mechanism, to help students create, develop, justify, implement and evaluate building design solutions. The mapped process of the design project provides a worked example of integrating critical thinking into PBL in Environmental Building education, which should contribute to future debate on PBL in the wider higher education community.*

**Keywords:** critical thinking; environmental building; project based and problem based learning; student learning

**Andreja Drobnič Vidic**

554–563 Assessment in Problem-based Learning Incorporated into Traditional Engineering Education: Difficulties and Evaluation

*Assessment in problem-based learning (PBL) incorporated into traditional engineering education should lead students to fulfil the PBL aims. Using process and outcome-oriented assessment methods, we introduced an assessment scheme that addresses all eleven outcomes of EAC 3 in engineering and contains individual and group assessment. The present article aims to expose and present difficulties of group assessment with 'problem projects' integrated in the assessment scheme. 'Problem projects' could provide an objective picture of individual student's knowledge, skills and progress if they are used in combination with other assessment elements from the scheme. The assessment scheme was used in an experiment, where PBL and traditional instruction were compared in an introductory statistics course. In the experiment, significant difference in students' achievements across 'problem projects' was observed. Despite difficulties in assessment the results encouraged us to use PBL also in other subjects.*

**Keywords:** engineering education; problem-based learning; assessment; evaluation of teaching method

**Ersun Iscioglu and Izzet Kale**

564–572 An Assessment of Project Based Learning (PBL) Environment Based on the Perceptions of Students: A Short Course Case Study on Circuit Design for VLSI

*Project based learning has drawn attention as a considerably popular approach especially in engineering education. According to many researchers and academics, it gives profoundly beneficial results for engineering education as a result of the features it incorporates. Success of any application is closely related with how the application is perceived. This study assesses a Project Based Learning (PBL) environment designed as a short course based on student perceptions. The study was dealt with as a qualitative research methodology and designed as a case study. Data gathered as a result of the study was dissolved with descriptive analysis. As a result of the study it was determined that students believe that this approach has provided benefits for them in the issues of bringing in responsibility, increasing their motivation, learning deeply, learning by doing (experiencing), applying theoretical knowledge in practice, improving their problem solving skills, seeing real-world problems, being informed about their own learning styles, improving the feeling of self-confidence, performing time and project management effectively.*

**Keywords:** Project Based Learning (PBL); short course; engineering education; circuit design for VLSI course

**Anette Kolmos and Jette Egelund Holgaard** 573–583 Responses to Problem Based and Project Organised Learning from Industry

## Part II

# Contributions in: Microprocessors, Programming, Applications of Physics, Statistics, Students' Motivation, Stress, Belonging, Curriculum Development, Sustainability, and Innovation

**U. Meyer-Baese, Guillermo Botella, Encarnación Castillo and Antonio García**

584–592 A Balanced HW/SW Teaching Approach for Embedded Microprocessors

*Currently popular textbooks on Embedded Microprocessors are analysed in depth and reveal the inherent weaknesses of these books. For example, while even advanced hardware (HW) concepts are presented, the textbooks fail to provide descriptions about the development of software (SW) tools that put these microprocessors ( $\mu$ Ps) to work. Conversely, we provide an intimate knowledge of the close relationship between the  $\mu$ P design and the development tools with two teaching modules based on an architectural description language (ADL). The URISC model (popular since the IJEE paper 20 years ago) and the Educational RISC (ERISC) process models are developed in an iterative refinement of the instruction set. For all intermediate steps, development tools (assembler, linker, loader, C compiler) are generated which teach students the basics of embedded processor theory and design procedure. The processors are debugged using three example programs, synthesized to HDL for ASIC/FPGA designs, and are tested on popular Altera and Xilinx University development boards to offer hands-on design experience.*

**Keywords:** RISC; embedded microprocessor; FPGAs; ADL

**S. Ratnajeevan H. Hoole**

593–601 Programming Skills in Graduate Engineering Classes: Students from Disparate Disciplines and Eras

*In many graduate engineering classes there are often present students who meet prerequisites in programming but are rusty because it was a long time ago or they learnt an outdated language. In courses such as mathematical methods, finite elements, and power engineering there are students from different engineering disciplines; electrical engineers having programming as an ABET accreditation requirement, others not. Recent graduates are more sophisticated programmers than older ones. The problem is to bring the students up to competency without vitiating the content of the course to be taught so as to enhance it with modern computational methods. This paper describes an initial two-week MATLAB-based module on matrix equation solution that was used in four courses over five semesters at Rensselaer Polytechnic Institute. This module was within the scope of all four courses and, given MATLAB's ease of use and the students' mature standing as graduate students with resources among fellow students, it was used successfully (as a low-level programming language rather than a simulation tool as in much of the literature) to train even those who had never programmed*

before. Programming was thereupon used to enhance the engineering courses through computational exercises and in the process refine students' new programming skills further. A survey confirms the benefits.

**Keywords:** programming; prerequisites; programming language; education; matrix computation; MATLAB; accreditation; ABET

**Jorge Bonache, Carmen Cousido and Wilmar Hernandez** 602–611 An Educational Methodology to Interpret the Entropy of a Source Based on the Analogy between such an Entropy and the Mechanical Energy

*This paper describes a seminar within the work unit 'Introduction to the Entropy in Communications' in the Statistics and Stochastic Processes course. During the seminar the students study the entropy of a discrete source, its interpretation as potential information, and the parallelism with the law of conservation of energy. A detailed analysis of the singularity that represents the case of a uniform source distribution is carried out and analogies made with the principle of conservation of mechanical energy. In addition, the intuitive characteristics of the seminar are highlighted, as well as its gradually increasing development, carrying out successive generalizations. The methodologies used in the seminar allow the students to discover for themselves an interdisciplinary model of learning as well as showing them how to use computer simulation as a learning strategy in order to achieve the learning objectives.*

**Keywords:** entropy; information theory; law of conservation of energy; computer simulation

**J. B. Lopes, C. Viegas and J. P. Cravino** 612–627 Improving the Learning of Physics and Development of Competences in Engineering Students

*Engineering students should start being prepared for the demands of their profession from the early introductory courses. However, introductory physics courses often have little connection to the real world of engineering. Our work proposes a way towards meeting this objective: first, by a carefully planned curriculum, which must clearly inter-relate the desired learning outcomes with contextualized real-world tasks, and aligned with the students' assessment; second, by a careful mediation of the students' learning in the classroom, stimulating a healthy social learning environment, where students develop real work and overcome natural difficulties in order to construct their knowledge and develop the intended competences and abilities. This work took place in a Portuguese Polytechnic School of Engineering during four years; the results point to an incremental improvement, not only in the historically low pass rates, but also in students' satisfaction. In those classes where teacher mediation was varied and more significantly used to address the needs in students' learning, the results point also to the development of higher level competences.*

**Keywords:** introductory physics; engineering education; teacher mediation; students' learning; students' competences

**J. Gil, A. L. Pérez, M. I. Suero, F. Solano and P. J. Pardo** 628–641 Evaluation of the Effectiveness of a Method of Active Learning Based on Reigeluth and Stein's Elaboration Theory

*Several studies have shown that methods of active learning are more effective for learning the concepts of physics than traditional methods. We propose an active learning method based on the Elaboration Theory of Instruction applied to topics of Geometrical Optics. The proposal was tested on a sample of 202 students distributed in eight natural groups, corresponding to classes of pre-engineer year secondary education ("2nd Year of Bachillerato" in Spain). Four of these groups followed the proposed Elaboration Theory-based instruction sequence, and the other four followed the control sequence of instruction corresponding to their teacher's traditional methods. Pre- and post-tests were applied designed to detect preconceptions in Geometrical Optics. Their results confirmed that, at least in teaching material of Geometrical Optics, sequencing the content and activities according to the prescriptions of Elaboration Theory improves the quality of the students' learning relative to traditional methods because, amongst other capacities, it is able to correct their preconceptions on the subject.*

**Keywords:** research in physics; teaching methods; active learning; geometrical optics

**Reidar Kvadsheim, Mari Mehlen and Harald Kittang** 642–654 Web-Based Automatic Feedback on Assignments in Statistics: How Can it Help Students Learn Statistics and Universities Reduce Costs?

*A non-experimental study in 2005 suggested that immediate, automatic feedback on assignments helped to increase study motivation as well as pass rate among engineering students attending an introductory course in statistics at Oslo University College. In the follow-up study reported here we used an experimental design assigning the participants randomly to one of two experimental conditions: The 'web-supported' students received immediate, automatic feedback after having entered their responses to the assignments electronically. The 'paper-supported' students received written feedback on their paper-based submissions several days later. The findings contradicted the results of the non-experimental study: no significant differences between the groups were found with regard to final examination grades, study effort (with a certain qualification) and preferences with regard to the method for submitting answers. Running tutoring costs, however, were much lower for the web-supported than for the paper-supported students. Therefore, the present methodologically improved study strengthens the evidence that such learning support may help reduce running tutoring costs without significantly lowering final examination grades. Reinforcing this conclusion, certain remaining weaknesses in the experimental procedure open the possibility that the final examination grades of the paper-supported students have been inflated relative to those of the web-supported students. Moreover, questionnaire data and informal observations obtained during this experiment suggest that the tested web-based system of learning support can be combined with more traditional ways of promoting learning that may help increase learning with only a small increase in tutoring costs. These challenges with regard to the test methodology and the design of the learning-support system need to be addressed in new experiments.*

**Keywords:** web-supported learning; automatic feedback; immediate feedback; tutoring costs; statistics

**Wei Zhan and Jay R. Porter** 655–666 Using Project-Based Learning to Teach Six Sigma Principles

*An innovative approach of teaching Six Sigma, a tool widely used in industry, is discussed in this paper. The Six Sigma methodology was applied during a seven-week course project after the case-study of an actual Six Sigma project in a junior-level instrumentation course for a four-year engineering technology program at Texas A&M University. The students followed the Define, Measure, Analyze, Improve, Control (DMAIC) process to improve a given product design. Statistical analysis of final examination, course project, and survey results shows that the new approach is an effective way of teaching Six Sigma concepts.*

**Keywords:** Six Sigma; course project; project management; engineering education

**Josep M. Mateo-Sanz, Agusti Solanas, Dolors Puigjaner and Carme Olivé** 667–680 Refining Statistical Problems: A Hybrid Problem-Based Learning Methodology to Improve Students' Motivation

*Statistics is fundamental to many disciplines and plays a central role in Engineering and Sciences. To understand and apply statistics requires students to be highly motivated. Therefore, fostering students' learning and reducing dropout rates implies increasing students' motivation. We present a guided problem-based learning approach to teaching statistics in hybrid learning environments and we analyse its impact on students' motivation. We pay special attention at subdividing problems into small sections to obtain detailed sets of questions associated with specific concepts or procedures. This degree of detail guarantees that students can easily tackle these problems in virtual learning environments. In addition, thanks to the use of automatically generated log files, our proposal allows teachers to finely analyse the steps in which students have difficulties. We assess our proposal in terms of student satisfaction and motivation. The results show that although success rates are not improved, students' motivation for the subject increases. Consequently, our approach is a good choice to improve motivation and reduce the dropout rate in difficult subjects such as Statistics.*

**Keywords:** PBL; statistics; virtual learning environments; motivation

*This paper examines the main factors that affect the stress level of engineering students. Our questionnaire is based on the scale, Inventory of college students' recent life experiences (ICSRLE). Randomly collected data from 200 students are analysed with MINITAB14. The Six sigma techniques of Pareto Analysis, SIPOC Analysis, Cause and Effect matrix and Relationship charts are used to identify the most significant factors. It is found that the teachers' communication and marking skills are the most critical factors. The findings of this research underscore the importance of having a transparent marking system to the course's both inside and outside the educational institutions and to guide teachers in improving their communication and marking skills to reduce stress in students.*

**Keywords:** student stress; engineering students; communication skills; six sigma

**Denise M. Wilson, Philip Bell, Diane Jones** 687–698 A Cross-Sectional Study of Belonging in Engineering Communities and **Lisa Hansen**

*Few research efforts in engineering education study the impact of affect on student experience. However, a substantial number of interventions, research centers, and similar organized efforts seek to improve the strength and cohesiveness of the community in which the student spends a substantial part of his or her time. Belonging and the related affective sense of connection to community are viewed implicitly in these efforts as a positive attribute of the intervention, yet rarely are these improvements explicitly measured. This work reports the results of the sense of belonging (and community) of students within a variety of engineering education venues, using measures that have been previously validated in K-12 educational venues and whose validity is confirmed for the higher education, engineering populations studied herein. Differences between the local (immediate) community and the larger community to which the engineering student or faculty belongs have been analyzed in conjunction with the sense of belonging experienced by engineers in five academic venues including conferences, classrooms, and retreats. Overall, the results show that an engineering sense of belonging is highest in local (immediate) venues in which community building is part of the venue mission (along with transformative goals for engineering research education), but lowest in undergraduate engineering classrooms. The sense of belonging in the larger community to which the engineer belongs tends to be highest for faculty, then graduate students, then undergraduate students. Sense of belonging is also highly correlated to the psychological sense of community (PSC), technical competence, and feelings of being socially at ease. Faculty-student relatedness, a major player in student fulfillment, is less correlated to belonging but still (moderately) related.*

**Keywords:** belonging; psychological sense of community; affect; engagement; identity

**Timothy L. J. Ferris** 699–707 Bloom's Taxonomy of Educational Objectives: A Psychomotor Skills Extension for Engineering and Science Education

*Bloom's taxonomy of educational objectives has been a useful tool for many educators over several decades. Bloom's taxonomy divided educational outcomes into three distinct domains: the cognitive, affective and psychomotor; it provided a hierarchical taxonomy of outcomes in each of the cognitive and affective domains. Several psychomotor taxonomies have been developed for the K-12 level of basic skills development. These taxonomies are not particularly helpful in relation to development of professional level psychomotor-related skills. This paper presents a theory of the nature of knowledge and a taxonomy of psychomotor domain outcomes adapted to trade and professional level skills involving the practical performance of work.*

**Keywords:** Bloom's taxonomy; psychomotor domain

**Bhushan H. Trivedi** 708–715 Impact of Effective Pedagogy on Information Technology Students with Weak Academic Backgrounds

*In India today, many students in STEM disciplines at technical institutions below the top rank are seriously lacking in prerequisite knowledge and skills and motivation to learn. This paper reports on the implementation of a learner-centered teaching approach in an information technology program in such an academic setting. Learning objectives covering the full spectrum of Bloom's Taxonomy of Educational Objectives were used to guide the preparation of lessons, assignments, and examinations, and active and inquiry-based learning were used for lectures and assignments. Compared with previous students who had been taught traditionally, the students taught in this manner showed dramatically improved performances in analytical problem solving and critical and creative thinking, and they reported a greater interest in the subject and a greater level of enthusiasm about the lectures. Although there is still considerable room for improvement, the results indicate a great potential for proven learner-centered pedagogies to improve the chances of success for STEM students who are at high risk of failure in developing countries.*

**Keywords:** information technology education; active learning; learning objectives; inquiry-based learning

**John E. Speich, James T. McLeskey, Jr.,** 716–726 Curriculum Development for a Nuclear Track in Mechanical Engineering and **Mohamed Gad-el-Hak**

*With sponsorship from the US Nuclear Regulatory Commission, Virginia Commonwealth University (VCU) has developed a nuclear engineering track within its undergraduate mechanical engineering program. Eight courses from the mechanical engineering curriculum were replaced with nuclear engineering courses to create the track. For the benefit of other universities which may be contemplating a similar undertaking, the present article presents motivation for the track, justifies and describes the content of the nuclear courses that are included, and explains the courses that were replaced. In contrast to a stand-alone nuclear engineering bachelor's degree or a minor in nuclear engineering combined with a major in mechanical engineering, the VCU nuclear track equips graduates with both the breadth of an accredited mechanical engineering degree and a focused sequence of nuclear courses that is comparable to those taken in typical nuclear engineering degree programs. To achieve the goals of the track, the challenges were to determine which courses to remove from the curriculum while maintaining an accredited mechanical engineering degree, and which courses to add so that the new sequence compares well with typical nuclear engineering degree requirements.*

**Keywords:** nuclear engineering curriculum; nuclear engineering track; undergraduate nuclear engineering education; nuclear engineering at the bachelor's degree level

**Jennilee Harrison and Leidy Klotz** 727–734 Women as Sustainability Leaders in Engineering: Evidence from Industry and Academia

*Women are underrepresented in engineering education and practice, which limits the quality of the engineering workforce. One way to increase the participation of women in engineering is to emphasize subjects that appeal to them and require skills at which they are especially adept. A subject that may fit this description is sustainability. To examine whether the subject of sustainability may help increase the participation of women in engineering, the purpose of this research is to compare the percentage of women in selected sustainable engineering leadership positions with the percentage of women in general engineering leadership positions. Gender data were collected for the 'sustainability leader' at 79 of the largest design and construction companies in the U.S. Similar data were also compiled for engineering faculty attending workshops to share best practices for teaching sustainability. The percentage of women in the sustainability leader industry positions is much higher (39%) than the percentage of women in general management positions (8%). The percentage of woman attending the workshops is much higher (32%) than the percentage of woman engineering faculty (12%). Analysis of these results shows a statistically significant positive correlation between the subject of sustainability and increased percentages of women in engineering leadership positions. Increased consideration of sustainability in engineering education and practice could also help address the critical need to attract more women to the field.*

**Keywords:** sustainability; women; gender; leadership

*A Technology Innovation Mapping (TIM) Tool has been introduced in previous papers. The TIM Tool organizes the process of linking customers and technologies into a series of steps. The tool can be used by engineers, engineering, and others involved in technology commercialization. This paper focuses on the steps that organize the task of creating potential customers for a technology. The authors present an example technology to illustrate the key concepts of the TIM Tool.*

**Keywords:** technology commercialization; innovation; function mapping