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Guest Editorial

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Trends in Using Student-Centred Approaches in Mathematics and its Connection with Science, Technology, and Engineering 879-891

Drobnič Vidic

Problem-based, project-based and inquiry-based learning (PBL, PjBL, IBL) are student-centred approaches that emphasise interdisciplinary connection between subjects in all levels of education. After presenting the theoretical similarities and differences among these three approaches, we review the use of these approaches in mathematics education and its connection with science, technology, engineering (STEM). We analyse all articles from Web of Science database that examine one of the target approaches at various educational levels in mathematics and with its connection with other subjects. The distribution of the selected articles in 5-year periods allows us to delineate trends in the connection of math with science and other STEM subjects through student-centred approaches, and in the methodology used in the studies. Detailed analysis of selected articles with experimental design, where effect size is or can be measured, gives us an insight in common characteristics of science and engineering incorporations in mathematical education sphere. Our aim is to find out differences between students-centred approaches in mathematics as a sole subject, in mathematics connected with science, and in mathematics connected with all the STEM subjects from practitioners' point of view. Among other things our analysis reveals that integration of all the STEM subjects is a current trend in math education and it is mostly used with PjBL approach. The benefits of such STEM connection are naturally expected for mathematics as a knowledge base as well as for engineering as a field with wide range of knowledge applications. Finally, we encourage teachers and practitioners to implement such a school practice that conceives mathematics as making sense and to be applicable in a real life and in other fields of education – especially engineering.

Keywords: inquiry-based learning; interdisciplinary mathematics education; problem-based learning; project-based learning; STEM connection (science-technology-engineering and mathematics connection)

Repeated Use of Adaptive Comparative Judgment to Develop Student Understanding of Artificial Intelligence in Problem Based Learning Assignments 892-904

Lisa Bosman, Aasakiran Madamanchi, Scott Bartholomew and Vetria Byrd

Artificial intelligence (AI) is a rapidly developing field with growing importance in engineering, in particular, it serves as a means to better understand and manipulate big data. As educators look to develop more T-shaped engineers, where students have both a breadth and a depth of knowledge and skills, understanding artificial intelligence (AI) applications is extremely important due to its versatility. However, the literature is sparse in how to educate engineers on the use of AI applications. In this paper, the researchers examine the utility of a problem-based learning approach with the well-known supply chain management 'Beer Game' using adaptive comparative judgment (ACJ). ACJ is a mechanism for 'learning by evaluating' through formative iterative comparisons as students develop their understanding of AI applications in supply chain management. The guiding research question was as follows: *Does repeated use of adaptive comparative judgment (as a 'learn by evaluation' tool) lead to enhanced student understanding of artificial intelligence?* Findings provide evidence towards the effectiveness of the 5-week module to improve student perceptions and learning outcomes related to the intersection between supply chain management (SCM) and AI, but only when the treatment and control subgroups were "engaged" students who completed all module requirements. In other words, the use of ACJ 'learning by evaluation' was only found to be statistically significant for students who participated 100%; it was not found to be statistically significant for students who only partially participated. This is a novel finding that extends our understanding of the effectiveness of 'learning by evaluation' for problem-based learning assignments.

Keywords: Problem-based learning (PBL); artificial intelligence; adaptive comparative judgment

Collaborative Graphic Simulation Experience Through Project-Based Learning to Develop Spatial Abilities 905-916

Vicente López-Chao, Jose Luis Saorin, Jorge De La Torre-Cantero and Dámari Melián-Díaz

Engineering and architecture education deals with a great challenge, to develop students' spatial abilities. Although there is an innumerable list of three-dimensional CAD software that seems to overcome this need, the ability to mentally visualize their ideas allows providing solutions faster and in greater detail. At the same time, graphic subjects need to adapt teaching to favor skills such as teamwork and problem solving, while students face how to understand theoretical content that is abstract to them. This research explores a collaborative graphic simulation proposal through Project-Based Learning that responds to the set of needs to determine if the graphic simulation of a real object can improve the spatial skill. The quasi-experimental research involved 29 undergraduate engineering students. The CoGraphS scale was designed and validated to measure student perception towards their involvement in a collaborative graphic simulation and MRT and DAT tests were applied to measure pre and post spatial and mental rotation skills. Descriptive analysis and Student's t statistic were applied to define the sample perception and to verify the improvement of spatial abilities. Multiple linear regression analysis was conducted to examine correlations among PBL variables

and students' satisfaction with the process, result, motivation and communication. The results provide evidence of a positive relationship between the experience and the improvement of spatial skills. The manuscript contributes and discusses the influence of a series of variables that have not yet been widely discussed in the PBL in engineering.

Keywords: engineering graphics; spatial abilities; project-based learning

From Initiators to Free-Riders: Exploring the Spectrum of Female Engineering Students' Functional Roles in Project-Based Learning using Phenomenography

917-933

Juebei Chen, Jiabin Zhu and Tianyi Zheng

Collaborative learning has been proposed as a strategy to improve engineering female students' learning by providing the opportunities to work in a supportive group. However, female students still face multiple challenges especially in a male-dominant group. To gain a deeper understanding on female students' team experiences and thereby improve their performance, this research investigates the spectrum of team roles among female engineering students in project-based learning. Using a phenomenographic approach, which features investigating the variation of experiences, we mapped twenty-one female engineering students' diverse roles in three dimensions-task, social, and individual roles in a qualitative manner. A variety of roles were identified, ranging from initiators, task assistants, to task outsiders (task), from coordinators, conflict mediators, communication outsiders (social), and from challenger-lovers, recognition-seekers, to free-riders (individual). Moreover, factors such as gender ratio and group dynamics, were found to be associated with their role-taking. The exploration of female students' functional roles provided an overall understanding about the diversity in female students' functional roles and associated factors influencing their role-taking. Suggestions as related to group arrangement, task division and other aspects in PBL were discussed for future course design.

Keywords: Female engineering students; functional roles; project-based learning

Variation of PBL in Higher Education Within Engineering, Science and Mathematics

934-946

Bettina Dahl and Annette Grunwald

Aalborg University (AAU) in Denmark is one of the universities in the world that practises problem-based learning (PBL) in all study programmes at all faculties. The PBL principles are broadly defined, and each study programme practices PBL in its own way within these frames. In this paper, we study how differently PBL is practiced within the science, engineering and mathematics areas at AAU. In particular, we analyse 21 AAU Bachelor theses in a selection of different engineering, science, and mathematics study programmes, to explore which types of problems from the discipline the students are addressing in their projects. We exemplify this through an analysis of recent Bachelor theses from Chemical Engineering and Biotechnology, Building and Construction Engineering, Mechanical Engineering, Mathematics, and Biology, respectively. The focus is on which types of problem from the discipline the students work with. The research methodology is documentary analysis of curricula and the theses. We first, through a deductive analysis, apply the four shadows of problems' theoretical framework to categorize the problems. This showed that 18 of the 21 theses can be categorized as concerning a contrast problem. This is the case for all five fields of study. Secondly, a more detailed inductive content analysis of these 18 theses' problems showed that these 18 problems had a great variation, and we were able to identify five specific types of contrast problems among these 18 theses.

Keywords: Bachelor thesis; problem-based; problem variation; project work; engineering, science and mathematics education

Challenges Faced by Students in Adopting PBL in Environments of High Social Inequality: An Instructors' Perspective From a Latin American Case

947-958

Carolina Rojas-Córdova, Moira Negrete-Fernández, Ariel Areyuna-Santiago, María Hilda Flores, Mariela Tapia and Ariel Salazar-Araya

Engineering education has widely adopted project-based learning (PBL) because of its effectiveness in developing students' capabilities to face society's current, complex challenges. However, both students and professors are challenged while adopting PBL. These challenges increase when students' technical and social backgrounds are highly heterogeneous within a course, as seen in many Latin American engineering faculties due to economic and social inequalities. Using the case of an engineering faculty from Latin America, in this study, we examine specific barriers caused by students' social heterogeneity and how professors handle these barriers in fresher courses. Specifically, we propose that heterogeneity generates asymmetries in students' technical backgrounds, social competence, and engagement, which professors address using scaffolding, teamwork, and identification mechanisms. Theoretically, this study partly reveals the particular dynamics that engineering professors face in Latin American countries. Alternatively, from a practical standpoint, we provide engineering professors with insights into implementing PBL in these environments.

Keywords: engineering education; project-based learning; barriers; heterogeneity

Engineering Teachers' Professional Learning and Role Identity Change in An Intercultural (Study-Abroad) PBL Programme

959-973

Niels E. R. Lyngdorf, Youjin Ruan, Juebei Chen, Xiangyun Du and Anette Kolmos

This study follows three Chinese university instructors' learning and role identity change in a six-month Problem-Based Learning (PBL) professional learning programme in Denmark. Data sources include individual progressive portfolios and two rounds of interviews. Data analysis using the *Dynamic Systems Model of Role Identity* indicates that all three participants experienced change in all four dimensions of the model: ontological and epistemological beliefs, purpose and goals, self-perceptions and definitions, and perceived action possibilities, resulting in changed teacher role identities. Furthermore, the role of the intercultural context of the programme in triggering enablers and/or constraints for learning was also studied. It was found that beliefs about cultural community and "othering" in some cases acted as initial triggers for learning and motivation, while, in other instances, beliefs about cultural differences could be a constraint. The results provide evidence of the effectiveness of using a PBL methodology to organise professional learning activities and facilitate teacher role identity change and explore the roles of culture and interculturality in relation to the DSMRI model.

Keywords: Chinese engineering teachers; teacher role identity; PBL based pedagogical development; intercultural/study abroad; Denmark; DSMRI

A PBL-Based TRIZ Training Approach for Improving Inventive Competency of Engineers in Workplace

974-989

Wei Liu, Runhua Tan, Zibiao Li and Bojun Yang

How to improve inventive competency of engineers in workplace plays a significant role in competitive advantages of companies. This paper presented and validated a PBL-based TRIZ training approach for engineers in workplace aiming at enhancing their inventive competency using the integration of TRIZ and PBL-based educational techniques. To do so, after a systematic review of related studies, a new TRIZ training approach is fabricated with seven specific steps built on the framework of PBL. Subsequently, research data collected from 95 participants is used to validate the practical proposed TRIZ training approach. Statistical analysis is conducted based on pre-training, during-training and post-train inventive outcomes of the research sample that are measured by a set of patent-based indicators. Comparing analysis results have indicated that the proposed TRIZ training approach has evidently increased the inventive outcomes of participating engineers. Moreover, regression results revealed that the position closeness to the new product development and the patent applying experience are two most significant positive influencing impactors on the effectiveness of the proposed approach. Lastly, this paper also highlights several implications for educating TRIZ to engineers in workplace and limitations to initialize studies in the future.

Keywords: TRIZ; PBL; inventive competency training; engineers training; training in workplace

Section II

Contributions in: Active Learning, STEM, Problem Solving, Gender, First Year Students, Living Community, Diversity, PBL, Quality Assurance, Faculty Development, Assessment, Prediction Model, Retention, Interdisciplinary, Extended Curriculum Program Blended Learning, Electrical Engineering, Material Science and Engineering

An Analysis of an Instructional Development Workshop to Promote the Adoption of Active Learning in STEM: Potential Implications for Faculty Developers

990–1009

Laura J. Carroll, Cynthia J. Finelli, Michael J. Prince, Matthew C. Graham, Jenefer Husman, Madison E. Andrews and Maura Borrego

We developed an instructional development workshop for science, technology, engineering, and math (STEM) instructors in higher education to promote their adoption of active learning. Our workshop design was based on a proposed framework for motivating adult learners consisting of five elements: (1) expertise of presenters, (2) relevance of content, (3) choice in application, (4) praxis, and (5) group work. We assessed the participating instructors' attitudes (i.e., motivation to use active learning and intentions and motivation to use strategies to reduce student resistance to active learning) immediately before and after the workshop and again five to six months later. We also assessed participants' satisfaction with the workshop. Analyses of our data provided evidence of a change in participants' motivation to use active learning and both their intentions and motivation to use strategies to reduce student resistance to active learning following the workshop. Our quantitative findings and thematic analysis of survey results support the use of the proposed framework for designing instructional development workshops for STEM faculty. The results also show short-term instructional development workshops can be effective and suggest caution in extrapolating immediate post-workshop assessment to the longer-term.

Keywords: professional development; instructional development; instructional change; active learning; student resistance

Characterizing Back-of-the-envelope Problem-solving in Engineering

1010–1020

Gabriel Murillo-Gonzalez and Eric W. Burkholder

Back-of-the-envelope (BOTE) problems are informal estimation problems frequently used by engineers to come up with fast and simple estimates for solutions to much more complex problems. Although these problems are well-known within engineering, they remain essentially undefined in the academic literature. This poses a problem for instructors and managers who try to teach BOTE problem-solving, because one cannot teach something that one cannot measure or characterize. To this end, we interviewed 11 engineers from a range of subdisciplines about how and why they use BOTE calculations in their work. We chose to characterize BOTE calculations in terms of the cognitive decisions made by the solver at each stage of the process. We found that BOTE calculations could be characterized in terms of a limited set of 14 decisions. By identifying these decisions, we have identified the decisions one must practice and receive feedback on to learn how to solve BOTE problems.

Keywords: problem-solving; estimation; expertise

Impact of Grade Penalty in First-Year Foundational Science Courses on Female Engineering Majors

1021–1031

Alysa Malespina and Chandralekha Singh

Many frameworks have been put forth for why women continue to be underrepresented in engineering professions. Here, we introduce a framework that posits that grade penalty in first year foundational science courses for engineering majors may be particularly damaging to female students who do not have role models and are questioning whether they have what it takes to excel in an engineering major and career due to pervasive stereotypes. In order to quantify grade penalty, we define Average Grade Anomaly (AGA) as the difference between a student's grade in a course under consideration and their grade point average (GPA) in all other classes thus far. An AGA lower than students' expected grade based on their GPA is a grade penalty and higher than expected grade is a grade bonus. Our framework posits that female engineering majors are more likely to be negatively impacted by a grade penalty in their first-year foundational science courses since their academic self-concept as an engineering major hinges on them securing a certain grade. In the study presented here, we examine AGAs of 6,028 first-year engineering students across a number of required courses. We find that students tend to receive grade bonuses in engineering and English composition courses, and grade penalties in physics, chemistry, and math courses. These courses with grade penalties tend to be large, lecture-based courses. We also find that in physics courses, women have larger grade penalties than men, whereas in chemistry and math, men have larger grade penalties. Thus, physics courses may be most damaging to women out of all of the courses in which they receive grade penalty. We hypothesize that women's decisions to pursue an engineering major and career may be affected more by the grade penalty received in foundational science courses than men's due to societal stereotypes about who can excel in engineering and access to other coping mechanisms that may help to rationalize lower-than-expected grades. Furthermore, the grade penalty measure can be easily computed by the engineering programs concerned with equity. Finally, we provide recommendations for how engineering programs may mitigate grade penalties in the foundational science courses, which may be particularly damaging to women.

Keywords: gender; equity; grades; grade penalty; grade anomaly

The Impact of a Living Community for Women Engineering Undergraduates

1032–1043

Siqing Wei, Kerry L. Meyers, Victoria Goodrich and Jazmin Jurkiewicz

Many approaches for improving engineering student retention have been considered, including living learning communities (LLCs). The current study is focused on evaluating the benefits of intentional housing placement of female students to increase retention in engineering (the "living" portion of an LLC), operationalized by three-year retention to graduation referred to herein as "engineering living community." At the residential university studied, intentional placement of women engineering intent students has taken place since the early 2000s. Using institutional data of a private university, retention of women engineering students is compared to women who were not placed in a residence hall with other engineering students from 2005–2016 by examining the descriptive statistics and conducting statistical analysis, including Kruskal-Wallis rank-sum test and linear logistic regression. Additionally, a short survey was sent to current women engineering students to ask specifically what impact their residential hall placement had on their decision to continue in engineering. Results show that students placed in an engineering living community were significantly more likely to be retained to their third year in engineering and on to graduation than those that were not in an engineering living community. The implication of this finding is that a living community without the added administrative structures of course alignments or formal mentorship can still offer substantial benefit to participants and are a no cost way to improve retention of women and potentially other underrepresented groups.

Keywords: living community; retention; female student; diversity; mixed method

Songxin Tan and Zixing Shen

The engineering field is changing rapidly. Engineers need to have multiple knowledge, skills, and abilities (KSAs) to stay current and relevant. Problem-based learning (PBL) can prepare engineering students to develop KSAs. The extant PBL research at the course level primarily examines the effects of PBL on learning outcomes measured by instructor-developed performance metrics and student self-reports. Thereby little is known about student perceptions of PBL learning experiences and processes. This study aims to bridge this gap. We conduct a case study on student learning experiences with PBL in an electrical engineering course. The quantitative and qualitative analyses of questionnaire data show that students had an overall good experience with PBL and reported positive effects of PBL on independent and interdependent learning. The student-centered approach helps develop a shared understanding between students and the instructor and contributes to the empirical knowledge of the learning experiences and processes of PBL. The study, therefore, provides engineering educators with deeper insights into PBL and practical guidelines in designing and implementing PBL in their courses.

Keywords: problem-based learning (PBL); student perspective; learning experiences; learning processes; case study; electrical engineering

Managing the Industrial Engineering Cooperative Program Process Using a Standardization Process Model

1056–1072

Emad Hashiem Abualsauod and Asem Majed Othman

This study provides a broad overview of the standardization process for a Cooperative Program (COP) through a case study in an industrial engineering (IE) department at a public university in Saudi Arabia. This study aims to investigate a systematic and consistent approach for developing, implementing, and measuring outcomes of COP policy and procedures. To this end, this study presents the process used to develop a Cooperative Program Handbook (COPH) using a standardization process model. The developed COPH includes all of the requirements, standardized process flows, expected deliverables, assessment of COP learning outcomes, mapping with ABET Student Outcomes (SOs), and continuous improvements for the COP experience. The COPH was implemented for two consecutive academic years, 2019 and 2020, in the industrial engineering undergraduate program of a public university in Saudi Arabia, in order to measure students' attainment of ABET SOs 3, 4, 5, and 7. As a result, the proposed model was successfully implemented and showed improvements and lessons learned relating to student attainment at each SO for the COP over the two academic years of implementation. The results show that the average achievement of SOs was 86.27% for direct assessment and 79.34% for indirect assessment. Afterwards, a questionnaire was conducted on 157 stakeholders to measure their satisfaction with the proposed approach. The results showed that the average overall weighted level of stakeholder satisfaction was 76.83%. It was observed that COP goals, stakeholders' roles and responsibilities, COP process flows and requirements, evaluation and assessment methods, and COP learning outcomes had a high impact on stakeholder satisfaction. Although the focus of this study was on an undergraduate engineering program in Saudi Arabia, the insights of measuring ABET SOs through this approach are quite generic and can be applied to other engineering schools beyond Saudi Arabia.

Keywords: Cooperative Program Handbook; Quality Assurance; Process Standardization; Continuous Improvement; Student Outcomes; Industrial Engineering Program; ABET Student Outcomes

Engineering Deans' Perspectives on the Current State of Faculty Development Programs in Engineering Education

1073–1091

Mark Huerta, Jeremi London and Ann Mckenna

There is little literature exploring the needs of engineering faculty and the resources available at engineering colleges to support faculty development. Engineering deans are key stakeholders within institutions well-positioned to discuss trends and practices in faculty development within engineering colleges, however their perspective has not been captured in the literature. The purpose of this exploratory qualitative study was to learn about the state of faculty development within engineering colleges through the perspective of engineering deans. A particular focus was placed on identifying salient faculty needs and resources available to support faculty development within engineering colleges. Semi-structured interviews were completed with 23 engineering deans representing three types of institutions: R1 public ($n = 8$), R1/R2 private ($n = 6$), and primarily undergraduate-focused ($n = 9$). A rigorous thematic analysis process was completed until a final codebook emerged with strong interrater agreement. According to the deans the primary needs for incoming faculty involved teaching, research, understanding expectations, time management, and connectivity. There were variances in the approaches and resources available at each institution especially in relation to mentorship. This study indicates that further investigating effectiveness of faculty development programs especially mentorship across the various stages of a faculty's career would be fruitful contributions to the engineering education community.

Keywords: faculty development; mentoring; institutional culture; qualitative methods

An Integrated Approach for Assessing Graduate Engineering Management Programs

1092–1105

Timothy G. Kotnour, John V. Farr and Catherine Vergopia

Professional degrees are critical to many universities because of their relevant connections to employers/industry and the ability to provide the university with an additional revenue stream. These programs need to be adaptive and flexible in terms of content and delivery modes and be stakeholder driven with a strong focus on quality, relevancy, and customer satisfaction. This requires a paradigm shift in the assessment philosophy. This paper explores the keys elements of assessment for these executive style programs. The assessment process must focus on both formative and summative assessment for student learning, student satisfaction/value, program delivery, and employers perceived value in addition to the traditional student learning outcomes. We present a case study to demonstrate an integrated assessment approach. We share the details of this integrated approach with the goal that program directors can use this framework or elements of to adapt their current assessment approach.

Keywords: professional programs; formative assessment; summative assessment; assessment

Practical Prediction of Overall Performance from Formative Assessment Results of Engineering Students

1106–1115

Stephen O. Ekolu

In this paper, a new model was employed for probabilistic prediction of overall performance of engineering students. The model employs formative assessment results to estimate the summative assessment mark of an individual student. In the present study, statistical evaluation of predictions was conducted using data of seven (7) examination events involving 441 students studying bachelors and master's degrees of civil engineering programmes. The other key variables of the data comprised different class sizes, and heterogeneous classes containing students of varied academic performance levels. It was found that the model gave realistic predictions with a good to excellent level of accuracy. The range for summative performance results of students whose formative assessment marks fall between 50 to 70%, can be accurately estimated. The model may be used to inform policy frameworks targeted at promoting students' performance and throughput.

Keywords: prediction model; formative; summative assessment; examination

Retaining Engineering Students: A Case Study at Aalborg University

1116–1129

Henrik Worm Routhé and Pia Bogelund

With an increasing need for engineering people throughout the world, high educational dropout rates are becoming a serious problem. The field of dropout and retention often inquires into why students leave. The focus in this article is the positive and institutional angle – what does it take for a higher education engineering program to retain engineering students? To investigate this overall research question of what actually works at a program level, an engineering program doing well regarding retention, is singled out, the relatively new Interaction Design (IxD) program, to explore the reasons why and compare with existing knowledge

within the field. The question guiding this exploration is: *What is it that the IxD program does well regarding retention?* The case study applies an explanatory mixed methods approach based in a review of successful studies on retention. Qualitative data are used to design the questionnaire and to substantiate the quantitative results. The questionnaire was sent out to all students from 1st, 3rd, 5th and 7th semester. Alongside this, we also interviewed staff. Aligning expectations with stakeholders outside and inside the university, an internal, progressive logic across the curricula of the entire program, a problem- and project based learning approach and extracurricular student groups across the semesters support both the academic and the social integration of the students. This piece of work draws forward the importance of alignment and the need for continuous expectation reconciliation between students and the university as a key issue in what works in retention beyond active group-based learning and as a continuous focus and activity on the part of the university.

Keywords: retention; engineering education; interaction design; sense-of-belonging; professional and social integration; PBL

Students' Attitudes Toward Interdisciplinary Learning: A High-School Course on Solar Cells

1130–1140

Aharon Gero, Heba Essami, Ofer Danino and Lior Kornblum

Due to the lingering lack of engineers in the Western world, universities are trying to attract candidates for undergraduate engineering programs through a variety of educational activities. One of the topics at the center of this effort is renewable energy in general and solar energy in particular. Recently, a unique 20-hour interdisciplinary course on solar cells was developed. This course, combining sustainability, physics and electronics, was designed to expose twelfth-grade students with appropriate backgrounds to advanced technological applications of theoretical physics in the context of renewable energy and to arouse interest in them. The aim of the research described here was to characterize students' attitudes toward interdisciplinary learning that combines science and engineering in general and toward the course in particular. The study, which used quantitative and qualitative tools, involved 27 Israeli twelfth-grade students majoring in physics. The findings indicate that the course graduates hold positive attitudes toward interdisciplinary learning, both cognitively and affectively, and that the correlation between the attitude components is positive, moderate and significant. The students believe that the integration of science and engineering is natural, as it reflects reality. In addition, they argue that the combination is interesting and improves the understanding of the disciplinary content. As for the course itself, students claim that it is important, arouses interest, and enriches knowledge, but is also characterized by a high cognitive load.

Keywords: interdisciplinary education; students' attitudes; renewable energy; solar cells

Materials Selection by Competitive Analysis of Properties: A Laboratory PBL Experience in Materials Science and Engineering

1141–1150

José A. Pardo

The case study shown here was proposed by the author as the final teamwork activity for a Materials Science and Engineering course in the third semester of an Industrial Engineering degree. It was presented as an experimental problem on materials selection that the students had to solve by fabricating a piece with fixed dimensions and fulfilling three limiting properties. Specifically, these were thermal, electrical and mechanical requirements, chosen to rule out in principle most polymers, metals and ceramics, respectively. The experiment intended to emphasize that materials selection often involves a competition between properties, that leads to mutually excluding solutions. It was carefully designed as an ill-structured problem with no unique correct solution. Nevertheless, a composite made by appropriately combining two or more materials from the three classical families can fulfill the required conditions. The paper shows and discusses the particular solutions proposed by my undergraduate students. Along the search they found out a number of essential topics in Materials Engineering, such as the difference between surface and bulk properties, the ranges of service temperature of common materials, the problem of ceramic-metal bonding, or the main factors affecting thermal shock resistance. They had to purchase the ingredients and fabricate the final samples by themselves, so inexpensive materials and rudimentary processing techniques were used.

Keywords: materials selection; problem-based learning; materials science and engineering

Improving Student Preparedness to Study Engineering: A Case Study in South Africa

1151–1158

Arthur James Swart and Danri Delpont

Students who complete their high school education are, at times, not adequately prepared for further studies in higher education. Some of these students struggle to meet the challenges associated with heavy workloads, extra laboratory work and a blended-learning environment. These underprepared students need additional academic support if they are to succeed with their university studies. One such support includes an additional year of study (part of an Extended Curriculum Programme aimed at improving student preparedness) prior to enrolling in a mainstream programme where they may study towards a Diploma or Bachelor's degree. The purpose of this article is to contrast the performance of these students to those who directly entered a mainstream programme, thereby highlighting the benefit of an additional year of study in helping students to become better prepared. This contrast is primarily based on their main examination grades that they achieved in a first-year compulsory module that forms part of a National Diploma in Electrical Engineering. Sixty-four students, with an additional year of study, are contrasted to 487 students who entered a mainstream programme directly between 2016 and 2017. Both groups of students struggled with questions relating to design which is correlated to the synthesis level in Bloom's Taxonomy. However, the average grade difference between the two groups never exceeded 10%, with the average being 6.9%. The contribution to education is the positive results achieved by these first-year students who enrolled for an extended curriculum programme, thereby supporting its continuance.

Keywords: university of technology; Extended Curriculum Programme; Mainstream Programme; first-years

Continuous e-Assessment of Student Learning Outcomes in a Multi-Agent Blended Learning System

1159–1178

Salah Hammami

Continuous e-assessments of Student Learning Outcomes (SLOs) is a central feature of education as it provides accurate and complete status of the students' outcome achievement. However, the existing continuous e-assessment methods are inherently macroscopic as they do not persuade continuous improvement in SLOs during their study period of each student. In this paper, we propose a Multi-Agent Blended Learning System (MA-BLS) to support Continuous e-Assessment Method (CAM) of SLOs. A fully automated CAM will be presented to enable continuous monitoring and evaluation of the progress of each SLO achievement which is covered in different courses during the entire period of an educational level and thus identify and suggest adaptive actions of improvement. A periodic Cumulative SLO-Transcript-like report (SLO-T) reflecting the progress of students' achievement is generated and delivered to the students accompanying their traditional transcript. This SLO-T will facilitate a microscopic status to learners, educators as well as employers thus enabling focus identifications of the capabilities and improvement opportunities for lifelong skills development. To validate the proposed method, we have conducted an experiment on a representative sample of 40 students representing 53% of a batch for two years of their study period. Both cumulative and perception assessments were conducted on the same sample. Finally, a students' perceptions and opinions collected through survey on self-confidence and motivation has revealed satisfactory results in consistence with the conducted cumulative achievement of their SLOs. This study contributes to advancing the field of technology-enhanced continuous e-assessment method of SLO and enhance teaching, learning process and improve academic programs.

Keywords: continuous e-assessment; students learning outcomes; blended learning; multi-agent; student learning outcome-transcript