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Special Issue

The Learner in Engineering Education

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Evangelia Triantafyllou, Olga Timcenko and Morten Misfeldt	944-955	Mathematics Learning by Programming in a Game Engine: Development of Knowledge and Student Motivation

This paper emerges from our research focusing on mathematics education in trans-disciplinary engineering programs and presents a case study in such an engineering discipline, namely the Media Technology program at Aalborg University Copenhagen, Denmark. In this case study, we substituted traditional mathematics assignments with a programming project in a game engine (Unity) when teaching the reflection and refraction vector calculation. The main concept of this approach was that students get simple projects in Unity, where mathematics is used for game mechanics, and they have to modify or further develop these projects. We conducted interviews with nine students who participated in this case study, and we analysed their mathematical work in Unity. For analysing students' mathematical practice, we employed the anthropological theory in didactics and the instrumental approach. The analysis of student responses and projects provided insights on how students apply knowledge from a mathematical model to implement a physical model. This study shed light on students' misconceptions and difficulties but also on opportunities for them to challenge their understanding. Moreover, it revealed that students do not always internalize the mathematical knowledge they acquire, and they may get correct results without understanding their mathematical meaning. We conclude that this type of activities is more beneficial for these students compared to mathematical exercises, because they challenge their understanding and confront them with their misconceptions.

Keywords: mathematics; the anthropological approach; instrumental genesis; game engine; programming; media technology

Ole Ravn and Lars Bo Henriksen	956-962	Engineering Mathematics in Context—Learning University Mathematics Through Problem Based Learning
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A theory-based approach to scientific research has an inherent tendency to become secluded from the ongoing problems and discussions of the surrounding society. A problem-based approach to research immediately involves this context of problems and discussions from the outset. In this article, we argue that education in university engineering mathematics should take its outset in contextual problems in order to provide a foundation for the skills and capabilities engineers need in their future job settings, whether it be research or development activities.

Keywords: engineering mathematics; problem based learning; university mathematics education

Liliana Fernández-Samacá, José M. Ramírez Scarpetta, Oscar O. Rodríguez and Edinson Franco Mejía	963-973	PBL Model for Single Courses of Control Education
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This study introduces a Project-Based Learning model (PBL) for single courses of a control system that is part of traditional education curricula. The PBL is applied to facilitate learning, encourage the development of transversal skills from technical areas, stimulate the use of active learning in engineering programmes, and respond to research questions about how to apply PBL in single engineering courses that is part of Traditional Education curricula. The model seeks to encourage the development of transversal competencies like decision making, problem solving, self-learning and information management. The PBL model considers not only the policies and facilities of the University in which is applied but also the culture and customs of the region in which the University is located, taking advantage of the context to recreate professional challenges. Likewise, the model takes into account the support resources of Traditional Education and proposes the design of new web-based and local resources to facilitate the PBL application, which involves various steps for the execution of a project that aims to solve a control problem.

Keywords: project-based learning; control education; transversal competencies

Problem-based learning (PBL) is widely used across the professional education sector and is now emerging in engineering education as both a viable and effective teaching and learning strategy. PBL originated some 45 years ago in medical education at universities in McMaster (Canada), Maastricht (Netherlands) and Newcastle (Australia) and since then has gained popularity worldwide in many professional disciplinary fields. The PBL approach, as presented in literature, supports a shift from teacher-directed, or centred, learning to facilitation of students' learning, thus shifting the focus to students' learning. Facilitation, as practiced in PBL, involves a different style of teaching compared to traditionally accepted styles, and from the experience of both students and lecturers, brings with its adoption challenges. Importantly, a skilled PBL facilitator, who is secure in their role, can contribute significantly to the effectiveness of PBL groups' work and thus to students' learning. This paper reports on a qualitative study, and its findings, concerning the experiences of academic staff and students at one institution, the German Malaysian Institute (GMI), in Malaysia. During interviews and focus groups, lecturers and students identified the challenges that lecturers face in effectively facilitating PBL. Analyses revealed two major themes that inhibit success: lecturers' and students' adaptation to PBL. These findings provide interesting insights into what is required to adapt to this mode of delivery.

Keywords: problem based learning; engineering education; PBL challenges; PBL adaptation

Project Based Learning (PjBL) has shown to be effective in engineering to acquire both professional and lifelong learning skills. Nevertheless, some authors assert it is not an easy instructional method to implement. It requires teaching skills and entails some difficulties for both students and teachers, specially related to the time and effort needed to put it into practice. In some countries, the implementation of PjBL has a limited scope, restricted to single courses that do not have a great repercussion in the curriculum. Moreover, some teachers tend to implement PjBL intuitively, based on their teaching experience instead of following important PjBL principles or instructional practices. To facilitate the proliferation and better establishment of PjBL in these countries, it is necessary to engage more teachers in best practices of this methodology, applying its main instructional principles and adequate educational theories. In this way, they could overcome the difficulties mentioned above and obtain better results in their experiences. This study is aimed at defining a method to design activities based on PjBL. This method guides teachers in the use of PjBL principles and several instructional design models. In particular, the method deals with the definition and articulation of an appropriate problem. In addition, it faces three fundamental issues in active learning and especially in PjBL: Students' Motivation, Supporting Students' Work and Autonomous Working. This proposal is specially focused on those academic contexts in which instructors are starting to use this methodology and students are not used to dealing with ill-structured projects, and consequently they could find important difficulties in its implementation. The method has been put into practice in three courses, where first results seem to be satisfactory according to a survey conducted by the Universidad Politécnica de Madrid. Results spanning the last six years of this survey have been analyzed. Currently, it is being used to implement a multidisciplinary project which covers four courses in a Master's degree. Finally, a collaborative online tool and teacher workshop further supports this method.

Keywords: project based learning; instructional design; motivation; PBL support

Problem-Based Learning (PBL) has become more popular in higher education over the past several years. It has proven to be effective in engineering education to increase students' motivation and the acquisition of skills required by the labour market and today's society. However, even when PBL is gradually introduced at an institution alongside traditional teaching, it is not perceived by students as an easy way to learn, especially when ill-structured, real problems are first introduced. Students can feel stressed, often because of their lack of both skills and previous knowledge, and they often prefer to focus their efforts on the final result and on passing their exams rather than the problem-solving process. To identify the difficulties that students have during PBL and to re-design instruction to increase students' motivation, this study used the MUSIC[®] Model of Motivation as a conceptual framework. This paper analyses students' motivation when PBL is introduced in a traditional-teaching institution, and discusses the main adjustments needed to increase students' motivation, engagement, and learning.

Keywords: problem-based learning; MUSIC Model of Motivation; motivating students; learner-centred approaches; engineering education

PBL is recognized as a model for learner-centered education. A goal of PBL is the performance of self-directed learning by the students during the solution of the problem. A recognized outcome of engineering undergraduate programs is the development of knowledge and skills necessary for the performance of lifelong learning; in other words, the development of self-directed learning abilities. This article explores the development of self-directed learning abilities by engineering students in a PBL curriculum. It aims to characterize how graduates understand and utilize self-directed learning at the juncture where they will be entering engineering practice. 27 participants were interviewed. All were at the end of their undergraduate PBL curriculum in the Iron Range Engineering program (Minnesota, U.S.). Open-ended interviews were conducted to explore the utilization of learning elements by the participants in their acquisition of technical knowledge. Interviews were transcribed verbatim and analyzed through multiple readings and the use of NVivo. Elements of self-directed learning were identified using the words and descriptions of the participants. Using their descriptions of interactions of the elements, a composite model of self-directed learning was developed. Learning theory from Illeris and the American Psychological Association are used to underpin the composite model. The outcome of the study is the insight into how PBL provides implicit development of self-directed learning abilities. This knowledge has potential value to curriculum decision makers considering the implementation of PBL, as well as to curriculum designers who would develop such curricula. The model itself has the potential for explicit instruction of self-directed learning.

Keywords: self-directed learning; PBL; lifelong learning; learning principles

In the calls for change in engineering education there is an increased emphasis for the student development of professional competencies. This paper looks at the student experience when the development of professional competencies is made to be an explicit learning outcome for students in a project-based learning (PBL) curriculum that is designed purposefully to develop them. This study builds on a previous quantitative study that indicated an increase in performance of the professional competencies by students who experienced the PBL curriculum. This qualitative study is focused on gaining an understanding of the student experience and also identifying which elements of the PBL curriculum affected the student professional competency development experience. Of equal interest, in the qualitative study, is to gain an understanding of the student experience in how they developed their importance for the professional competencies. The quantitative study indicates this was developed prior to upper division. The paper contributes to the literature on engineering education and serves to inform engineering education faculty and decision makers who are intent on transforming their respective engineering education systems through project based learning with the insights into the ways this PBL curriculum influenced the student development of professional competencies.

Keywords: project-based learning; professional competencies; reflection; and professional identity; outcome-based

This paper presents an empirical study based on the application of lean concepts to teaching and learning in student centered learning environments. It is based on findings from a pilot study carried out within an engineering course at the University of Minho, Portugal. The aim of this research is to contribute to the development and consolidation of the field of lean education in Higher Education. The main objectives of this study are to describe the model developed based on the application of lean concepts to teaching and learning and to analyze students' perceptions in regard to the application of this new model in the course of "Lean Enterprise". For the application of the model, a pilot study involving 31 students, during 12 sessions of 100 minutes each, was developed. Data collection was based on online questionnaires to students, applied at the end of each class (for process evaluation) and also at the end of the conclusion of the course (overall evaluation). Findings based on students' perceptions suggest that the model applied was useful and contributed to improve the teaching and learning process, while at the same time promoted continuous reflection of practice by the teacher. Some recommendations for future applications and improvements of the model are discussed in the paper.

Keywords: lean principles; teaching and learning; project-based learning; PDCA cycle; curriculum design

André Seixas De Novais, Messias Borges Silva and Jorge Muniz Jr. 1060–1069 Strengths, Limitations and Challenges in the Implementation of Active Learning in an Undergraduate Course of Logistics Technology

Teaching strategies have been used by several Higher Education Institutions to improve learning rates. In this context, international surveys have identified Active Learning as a methodology that provides students with the ability to be co-authors of their own learning process in which they occupy the central role. Professors also play an important role of process mediators through this methodology. Thus, strategies such as problem-based learning, collaborative learning, peer assessment, flipped classroom, among others, have been identified by experts as Active Learning approaches that increase learning rates. It so happens because it improves autonomy in reading, self-learning, discussions in pairs, information sharing, researches and discoveries. Despite the foregoing, Active Learning implementation in a higher education course is not an easy task, hence this research seeks answers to the following question: "What are the main strengths, limitations and challenges to implement Active Learning in a higher education institution?". In order to answer such a question, this paper aims to present a case study on the implementation of Active Learning in a higher education program. The object of this research is an undergraduate course in Logistics Technology of a Brazilian institution, with emphasis on its implementation actions, feedback from students and professors and experiences obtained from the discipline of Statistical Methods, which is considered as pilot project. In order to better understand its theory, a literature review of Active Methodology is going to be presented in the first and second sections, the third section is going to highlight some international experiences, its methods are going to be presented in the fourth section, and discussions of the case study and research conclusions are going to be shown in the fifth and sixth sections, respectively.

Keywords: active learning; strengths; limitations; challenges; implementation; higher education; logistics

Jette Egelund Holgaard, Aida Guerra, Anette Kolmos and Lone Stub Petersen 1070–1085 Getting a Hold on the Problem in a Problem-Based Learning Environment

When engineering students work in a problem-based learning environment they learn how to act as problem solvers by solving real life problems through the development of technological solutions. Problem solving is at the core of engineering practice and problem-based learning models have therefore been emphasised as powerful for engineering education communities to foster employability. However, the approach to problem-based learning differs considerably between different engineering institutions and one of the variables is the extent to which students develop their ability not only to solve pre-defined problems but also to identify, analyse and formulate problems themselves. This is important if the engineers of tomorrow are to work in a more holistic system perspective, as stressed by accreditation bodies, engineering education researchers as well as engineering academies. This conceptual paper presents a five-step model for students to identify, analyse and formulate a problem to be addressed from an engineering perspective. The model is the result of an iterative process, where theoretical as well as empirical inputs have pointed to creating a conceptual model for problem design for both students and staff, which is simple and concrete in its conceptual framing and walks the students through their first experience as problem designers in a sequential step-wise systemic manner. This model has gradually been appropriated to engineering communities by drawing on experience from students and staff in the problem-based learning environment at Aalborg University. Based on this, a five-step model for project design is presented initiating students to (1) relate to the theme, (2) map the problem field, (3) narrow down the problem, (4) analyse the problem in context and (5) formulate the problem. Experience shows that students can manage this step-wise model, but still there is a need to scaffold students during the process of developing problem design skills.

Keywords: problem-based learning; problem design; problem analysis; contextualisation; problem formulation

Jens Myrup Pedersen, José Manuel Gutiérrez Lopez, Marite Kirikova, Łukasz Zabłudowski and Jaume Comellas 1086–1097 Motivations and Outcomes: A study of an Intensive International Course

In this paper, we study what motivates students and university teachers to do intensive international courses, and how they evaluate the outcomes. The study is based on three years of an Erasmus funded Intensive Programme on "Implementing Europe's Future Broadband Infrastructure". It consisted of a course held each year 2012–2014 during two weeks of July, where 30–35 students and 10–12 teachers from the 4 participating universities would meet in one of the partner institutions. The course was organized with a week of course modules, followed by a week of project work based on real-life problems from companies, where students would work in groups mixed across nationalities and educational backgrounds. The topics of the first week, were defined to support the project work in the following week.

Each year, by the end of the course, all students and teachers filled out evaluation forms addressing motivation for participation and their assessed outcomes (teacher's motivations were only evaluated in the last year). This paper presents these results, together with the key learning points obtained during the three years.

We observe that the motivation for participating is quite balanced and include both academic and cultural factors. The students' travelling activities also emphasizes the "European experience", which is less for students in the host institution. Students following programmes not taught in English, also have an opportunity to practice a foreign language. The teachers are highly motivated by both personal and academic factors, especially by the desire to develop and experiment with new teaching methods. The analysis of the outcomes suggest that an international project with students and teachers from different cultures and learning traditions brings significant added value.

Keywords: problem based learning; internationalisation; intensive programmes; cross-disciplinary projects

Section II

Special Issue

Selected papers from STEM 2016 Conference, Beijing, China

Guest Editor

Feng-Kuang Chiang—Beijing Normal University, Beijing, China

Feng-Kuang Chiang, Shizhe Diao, 1098–1103 Effects of Hands-on Inquiry-Based Learning Using LEGO® Materials on
Haotian Ma and Yujun Wang the Learning of Eighth-Grade Physics Students

Physics instruction methods have long been a challenge for front-line teachers and instructors. To improve physics instruction, we have developed an innovative physics instruction method that uses LEGO® to facilitate the teaching of mechanics in middle-school physics classes. We expect the students to learn through construction and hand-on inquiry-based learning using LEGO® materials. After completing the curriculum design, lesson design, and other instruction-involved designs, we have conducted tests on two eighth-grade classes from junior middle schools in Beijing to verify the effect of the LEGO® instruction. The preliminary experiments have revealed improvements in physics study attitudes ($t = -3.099$, $p < 0.005$), physics learning motivation ($t = -3.794$, $p < 0.001$), and inner study motivation ($t = -2.243$, $p < 0.05$) of every member of the pilot study class comprising 35 students. On the basis of these results, we have revised our instruction designs and subsequently conducted experiments on the experimental class totaling 33 students. The physics grades of lower-grade ($t = -6.154$, $p < 0.000$) and middle-grade ($t = -4.971$, $p < 0.001$) students improved significantly. Moreover, attitude, usability ($t = -4.062$, $p < 0.000$), cognitive effectiveness ($t = -4.062$, $p < 0.000$), and LEGO® study attitude ($t = -2.384$, $p < 0.05$) improved remarkably. This article gives an account of the proposed innovative physics instruction design and makes an analysis of its effectiveness using the acquired data. A discussion on the teaching methods for innovative physics class instruction is also included.

Keywords: hand-on inquiry based learning; LEGO® materials; physics instruction

Tantan Dong, Yingying Zhang and 1104–1109 The Study of Teaching Mode in Building Blocks Based on K’NEX
Feng-Kuang Chiang

Building blocks are deeply loved by children. It has a great effect on children’s physical development, social cognition and so on. And it is also paid more and more attention by domestic and international scholars. But the research of building blocks mostly focuses on specific cognitive promoting function. However, the instruction of building blocks only remains at superficial level. This paper focuses on the teaching of building activity based on K’NEX blocks. And it puts forward the teaching mode in building blocks named Q4E. The details include questioning, exploring, explaining, expanding, evaluating. At the same time, the researchers held the activity named “Young Engineer” in China Science and Technology Museum to explore the feasibility of Q4E teaching mode. The study also wants to provide reference for the teaching of building blocks.

Keywords: K’NEX blocks; teaching mode; Q4E

Selline Ooko, Festus K. Beru, Samson 1110–1116 Contextualized Science Teaching and Student Performance: The Case of a
M. Nashon, David Anderson and Kenyan Girls Science Class
Elizabeth Namazzi

This paper is about a case study that investigated the impact of contextualized science teaching and learning on performance of a Form three (Grade 11) class in one of Kenya’s girls high schools. The class experienced nine weeks of contextualized science learning. This involved a full day visit to *Jua Kali* where they interacted with artisans. “*Jua Kali*” is a small-scale manufacturing and technology-based service sector where artisans manufacture equipment and other household items that are ubiquitous in everyday Kenyan culture. The visit was followed by organized classroom-based group discussions about what they had learnt and considered most relevant and meaningful. Following this highly engaging student learning discourse, their creativity and innovative abilities in science improved tremendously as reflected in the quality of class presentations and participation in the National Science Congress. Moreover, the school’s performance in the Kenya Certificate of Secondary Education (KCSE): a final national exam at the end of Form 4 (Grade 12) improved from a mean of 9.3 in the previous year to 10.4 in the intervention year ($p = 0.022$). This was further attributable to significant improvement in all science subjects: biology, chemistry, physics and mathematics. Besides the critical insights about the *Jua Kali*’s richness in scientific phenomena, there is also great potential for contextualized science experience to enhance students’ deeper understanding of science.

Keywords: jua kali; contextualize

Yang Dan, Xiaolin Zhang and 1117–1123 The Teaching Case Design of STEM Based on the Environment of
Luyao Wang Combining Museum and School—Water Resources Project

Under the guidance of STEM concept, the theme of this paper is “Designing water purification solution based on water pollution of China”. This paper integrates the resources from school, museum and water utility factory to develop a comprehensive learning practice, which involves multi-subject knowledge in biology, chemistry, math, physics and engineering. The students are guided to research the water shortage and pollution status in China, and independently inquire to find solutions for water purification through collecting water in daily life. During the overall process, students are collaborated to analyze issues, design the solution, practice, share ideas and assess the effectiveness. Consequently, the practice makes full use of local resources like water museum to add humanistic color to this study.

Keywords: formal and informal education; STEM; combination of museum and school activity

Pratim Sengupta and Marie- 1124–1134 Boundary Play and Pivots in Public Computation: New Directions in
Claire Shanahan STEM Education

In this paper, we introduce “public computation” as a genre of learning environments that can be used to radically broaden public participation in authentic, computation-enabled STEM disciplinary practices. Our paradigmatic approach utilizes open-source software designed for professional scientists, engineers and digital artists, and situates them in an undiluted form, alongside live and archived expert support, in a public space. We present case studies in DigiPlay, a prototypical public computation space we designed at the University of Calgary, where users can interact directly with scientific simulations as well as the underlying open source code using an array of massive multi-touch screens. We argue that in such a space, public interactions with the code can be thought of as “boundary work and play”, through which public participation becomes legitimate scientific act, as the public engages in the invention of novel scientific creation through truly open-ended explorations with pivotal elements of the code.

Keywords: public computation; STEM integration; complex systems; boundary play; open source