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Part I

Special Issue

Applications of Engineering Education Research—Part 1

Developing Engineering Competencies

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Jim Borgford-Parnell, Katherine Deibel and Cynthia J. Atman	748–759	From Engineering Design Research to Engineering Pedagogy: Bringing Research Results Directly to the Students

This paper describes how inductive pedagogical methods and findings from our design research were used in interactive engineering seminars to generate students' interest and motivation and to help students gain insight into design processes. We show how design process timelines, which are graphical representations used for mapping and analyzing individual design processes, can be effectively used as learning tools in the classroom. The activities and instruments we developed are explained, and we also relate our methods to established learning theory and pedagogical models, including topics in metacognition, project-based learning, and inductive learning.

Keywords: timeline; design process; engineering pedagogy; design thinking; design research; representations; inductive learning

Alan Cheville	760–770	Transformative Experiences: Scaffolding Design Learning Through the Vygotsky Cycle
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The motivation for this work was to create an engineering design course to develop students' abilities in electronic design. A 'transformative' design course was created by merging the design process found in most engineering design textbooks with the Vygotsky cycle. The Vygotsky cycle, drawn from socio-constructivist theories of learning, describes how both learners and their interpretation of knowledge are transformed by the learning process. Research identified elements of how students learn design, direct and indirect learning goals, and project constraints. A course model classified design learning through a taxonomy, identified aspects of design students lacked experience in, and scaffolded learning using the Vygotsky cycle. Following implementation of the design course, both quantitative and qualitative evaluation was used to measure student learning. Evaluation shows that although most of the direct and indirect course goals were met, there are aspects of design that students fail to master.

Keywords: Vygotsky cycle; capstone; design process; engineering design

Denny Davis, Michael Trevisan, Robert Gerlick, Howard Davis, Jay McCormack, Steven Beyerlein, Phillip Thompson, Susannah Howe, Paul Leiffer and Patricia Brackin	771–783	Assessing Team Member Citizenship in Capstone Engineering Design Courses
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Capstone engineering design courses exhibit a universal need to improve student teamwork performance while also documenting student teamwork achievements. To meet this need, the Transferable Integrated Design Engineering Education (TIDEE) consortium developed assessment instruments and companion scoring rubrics to target teamwork achievement in four areas: team relationships, joint work, individual work, and information management. Desired attributes of these instruments included transferability, practicality, reliability, user satisfaction, and robustness. Transferability was addressed by grounding the instruments in the teamwork literature and developing, piloting, and refining their use at multiple universities. A web interface for deploying and scoring the assessment instruments has supported sustainable, practical application of the instruments in a classroom setting as well as enabled design education research.

This paper describes initial deployment and pilot testing of one of the teamwork assessments—Team Member Citizenship. This assessment is unique from other developers' teamwork assessments in its combined features of: (1) being part of an integrated package of assessments for teamwork, (2) having a strong focus on reflective practice within teamwork, (3) having been tested for inter-rater reliability in scoring, (4) enabling faculty and peer feedback that supports students' growth in teamwork, and (5) providing data useful for grading and program assessment. Results demonstrate that this assessment provides data consistent with expectations, has reliability across rater scoring, and exhibits high levels of perceived value by student and faculty users. The teamwork assessments compile readily accessible research data about students' perceptions and performance of teamwork in design project environments. Additional assessment testing and data analysis are needed to further establish instrument validity and reliability.

Keywords: teamwork assessment; team performance; peer review; formative assessment

Rubén Rebollar, Iván Lidón, Juan L. Cano, Fernando Gimeno and Palle Qvist	784–794	A Tool for Preventing Teamwork Failure: the TFP Questionnaire
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This paper presents the process used to devise the Teamwork Failure Prevention Questionnaire (TFP Questionnaire), a tool that allows teams with problems in functioning to be detected early.

The TFP Questionnaire was formulated in a project management course at the University of Zaragoza (Spain). In this course, teams of five or six students have to manage a project for a real client. The questionnaire was then tested on students on this course and on a similar one at Aalborg University (Denmark).

This article analyses the psychometric characteristics of the TFP Questionnaire and then presents and discusses its results, before moving onto examine the implications of this research for engineering education research and engineering education in general.

Keywords: teamwork assessment; teamwork failure; functioning problems; project management

Globalization presents engineering educators with new challenges as they face the need for graduates who can function comfortably in an increasingly distributed team context which crosses country and cultural boundaries. Scaffolding learners to acquire professional attributes which transcend the solely technical places stress on traditional curriculum models. This paper analyses an Open Ended Group Project Framework (OEGP) situated in an action research program applied within the IT in Society course at Uppsala University. The approach results in conscious evolution of the course as an integral element of its design. It enables flexible planned educational change informed by a combination of learning theories and stakeholder input. In this paper we discuss the role of the research program in addressing the educational challenges we faced assisting students to develop global collaboration skills. The implications of combining this course with one at a partner institution in the USA and developing a global collaboration are also addressed. The paper concludes by summarizing the benefits of adopting an integrated action research and OEGP framework to support flexible course delivery in a global professional engineering context.

Keywords: Open Ended Group Projects; global collaboration; action research; engineering education research

Heidi A. Diefes-Dux, Judith S. Zawojewski 807–819 Using Educational Research in the Design of Evaluation Tools for
and **Margret A. Hjalmarson** Open-Ended Problems

Open-ended problems are an important part of the engineering curriculum because, when well designed, they closely resemble problem-solving situations students will encounter as professional engineers. However, valid and reliable evaluation of student performance on open-ended problems is a challenge given that numerous reasonable responses are likely to exist for a given problem and multiple instructors may be evaluating student work. The purpose of this paper is to present a concrete example of how educational design research, a models-and-modeling perspective from mathematics education, and multi-tiered teaching experiments are brought to bear in the design of valid and reliable evaluation tools for scoring team responses to complex problem-solving activities used in a large first-year engineering course in which teaching assistants evaluate student work. This on-going design study demonstrates how designing a package of evaluation tools (including rubrics, task-specific supports, and scorer training) based on the aforementioned educational research methods supports (1) sustained fidelity to engineering expert-identified characteristics of high performance across iterations of change to improve reliability, and (2) the implementation of planned iterations of the evaluation tools based on systematically collected data.

Keywords: design-based research; open-ended problem solving; evaluation tools

Tamara J. Moore and 820–830 Developing Measures of Roughness: Problem Solving as a Method to
Margret A. Hjalmarson Document Student Thinking in Engineering

The purpose of this study was to analyze the quality and content of responses to a nanotechnology modeling task in a first-year engineering course. Student teams had to determine a method for measuring the roughness of the surface of gold using digital images generated by atomic force microscopy. This study illustrates how modeling tasks of this type document student thinking, the variety of measures and methods students used in response to the task, and the range of performance demonstrating the ability of first-year students to apply their current ways of thinking to solve complex engineering problems.

Keywords: modeling; problem solving; nanotechnology; student thinking; authentic assessment

Tuba Pinar Yildirim, Larry Shuman and 831–845 Model-Eliciting Activities: Assessing Engineering Student Problem Solving
Mary Besterfield-Sacre and Skill Integration Processes

A Model-Eliciting Activity (MEA) presents student teams with a thought-revealing, model-eliciting, open-ended, realistic, client-driven problem for resolution. Here we extend the original MEA construct developed by mathematics education researchers to upper-level engineering coursework and introduce an ethical component. Our extensions also require students to integrate previously learned concepts as they gain new understanding. We propose that MEAs offer engineering educators at least two potential benefits: improved conceptual understanding and a means for assessing the problem solving process. However, these benefits will only accrue if the MEAs are properly implemented. Consequently, relative to the first we propose certain strategies, learned through experience, for successful MEA implementation, recognizing that this is not a simple task. In addition, we suggest using MEAs as assessment tools and illustrate how they can help analyze students' problem solving processes. Our findings are based on experiments conducted in different learning environments over a two year period at the University of Pittsburgh's Swanson School of Engineering. This paper should serve as a resource for those engineering educators and researchers interested in implementing MEAs.

Keywords: Model-Eliciting Activity (MEA); ethical reasoning; teaching engineering concepts; assessment of problem solving

Nikos J. Mourtos 846–859 Challenges Students Face in Solving Open-Ended Problems

Several core aerospace engineering courses at SJSU have been re-designed in an effort to help students develop problem-solving skills. This re-design includes (a) explicit definition of skills and attributes students need to develop to become capable problem-solvers, (b) inclusion of open-ended problems in each of several key, junior-level, core courses, (c) coaching students in the use of Wood's Problem-Solving Methodology, and (d) development of rubrics to evaluate student performance at each step of this methodology. The paper discusses the application of this process and, in particular, it presents an assessment of student performance in two courses: fluid mechanics and aerodynamics. The focus of this study is to identify specific difficulties students face while solving open-ended problems and specific steps they can take to overcome these difficulties.

Keywords: engineering problem solving; open-ended problems; assessment of problem solving skills; ABET criteria

Thomas Litzinger, Peggy van Meter, 860–868 Translating Education Research Into Practice Within an Engineering
Natalia Kapli, Sarah Zappe and Education Center: Two Examples Related to Problem Solving
Roxanne Toto

This paper describes how results from the education literature have been put into practice in two projects currently underway in an engineering education center. The projects are both aimed at improving problem solving. The first is being conducted in Statics, and the second in Fluid Mechanics course in Civil Engineering. The Statics project is grounded in a model that integrates literature on problem solving, representational transformations, and prior knowledge. This model was used to analyze students' problem solving in Statics so that key difficulties could be identified. Instructional modules were then designed to address those difficulties. The design of these instructional modules served as the starting point for modules in Fluid Mechanics. The primary literature used in the development of the instructional modules focused on cognitive modeling, self-explanation, and worked examples.

Keywords: problem solving; self explanation; cognitive modeling; worked examples

Steve Krause, Jacquelyn Kelly, 869–879 Effect of Pedagogy on Conceptual Change in an Introductory Materials
Amaneh Tasooji, James Corkins, Science Course
Dale Baker and Nancy Purzer

In this paper on research-to-practice we have addressed the question of what the effect of different pedagogies would be on conceptual change and repair of misconceptions or 'impediments' of different origin. This has been done by measuring conceptual change over a semester with a Materials Concept Inventory (MCI) for four introductory materials science courses taught by the same instructor who employed four different pedagogies in 2002, 2003, 2007, and 2009. Conceptual change theory was used to frame the overall study using

results of gains from particular MCI questions. These questions were selected since they each represented a prototype that fit Taber's five categories of the types of impediments that underlie the origins of different types of misconceptions. The degree of conceptual change achieved for the four different types of pedagogies was analyzed using Chi's recently published schema for characterizing the effectiveness of different active learning activities based on hypothesized underlying cognitive processes. In applying Chi's framework to MCI results for conceptual gain for the four pedagogies, they were ranked as follows: interactive with hands-on activity (concept sketching) > interactive with sorting activity (concept-context sort with no hands-on) > interactive discussion only > passive (lecture). Thus, the results agree in general with Chi's predicted effectiveness of learning, except that hands-on activities produced the most conceptual change as measured by the selected MCI questions. Overall, in this research-to-practice practice paper we have addressed, with a limited set of results, the question of what effect different pedagogies have on conceptual change and repair of misconceptions or 'impediments' of different origin. The results indicate that it may be possible to use these principles to design and create classroom environments, instructional materials, and activities that are intended to elicit in students cognitive processes and learning mechanisms that result in different degrees of conceptual gain in materials science and other engineering disciplines.

Keywords: misconceptions; conceptual change; learning impediments; teaching effectiveness; pedagogy

Michael J. Prince, Margot A. S. Vigeant, 880-890 Assessing Misconceptions of Undergraduate Engineering Students in the Thermal Sciences
and **Katharyn E. K. Nottis**

This study presents preliminary results of a multi-year research project to identify persistent misconceptions held by undergraduate engineering students in the core engineering sciences of thermodynamics and heat transfer. This report lays out the phased development of valid and reliable concept inventories to assess the prevalence and persistence of these misconceptions. The inventories exhibit reliability and validity levels that allow them to be used for research purposes. Student performance on the instrument from several undergraduate engineering programs demonstrates the existence of two specific misconceptions: (1) students frequently confound factors which determine the rate of heat transfer and the amount of heat transfer and (2) students often misconstrue the impact of entropy on the efficiency of real systems, specifically believing that the only barrier to 100% thermal efficiency is friction and heat losses. Prepost measures of students' conceptual understanding demonstrate that significant misconceptions persist after instruction in the relevant undergraduate thermodynamics and transport courses.

Keywords: heat transfer; thermodynamics; misconceptions

Timothy L. J. Ferris, Elena Sitnikova and 891-899 Building Graduate Capabilities to Communicate Research and Plans
Andrea H. Duff Successfully

This paper describes a strategy used to develop skills in research and communication among a cohort of postgraduate masters students. This took place in Engineering Research Practice (ERP), where most of the students were international with English as an additional language (EAL). The paper evaluates the combined effect of a change in course assessment processes and the introduction of a program of English for Academic purposes (EAP). We determined that tightly scaffolded curriculum and assessment design, combined with discipline-specific writing support, resulted in higher quality work.

Keywords: engineering research methods; scaffolded assessment; communication skills; international students

Jonathan Stolk, Robert Martello, 900-913 Engineering Students' Definitions of and Responses to Self-Directed Learning
Mark Somerville and John Geddes

In this paper we present the results of a study on engineering students' characterizations and critiques of self-directed learning experiences in their classrooms. Using a social-cognitive conceptual framework for examining self-directed learning processes, we analyze qualitative survey responses from a gender-balanced group of engineering students at a small, private engineering college. The data indicate that students believe self-directed learning focuses primarily on cognitive tasks associated with planning and monitoring the self-directed activity. Motivational considerations are frequently cited as significant positive aspects, while behavioral aspects such as goal setting and resource acquisition are the most commonly noted negative aspects. The survey results suggest that reflection tends to be undervalued both by students and by instructors, that motivation is key for creating positive self-directed learning experiences, and that there is a need for instructors to develop an improved ability to deal with the challenges that arise when students are asked to engage in self-directed learning processes.

Keywords: self-directed learning; lifelong learning; student autonomy; self-regulated learning; self-determination

Linda Vanasupa, Jonathan Stolk 914-929 Application of Self-Determination and Self-Regulation Theories to Course Design: Planting the Seeds for Adaptive Expertise
and **Trevor Harding**

The paper is grounded in the premise that learning occurs within a dynamic system of social and ecological interactions in the learning environment. Our intent is to open the conversation about how we, as engineering educators, design effective learning experiences for this dynamic system, particularly in light of the deeply ethical, adaptive expertise required of today's graduates. Drawing from two well-researched theories of psychological development (self-determination and self-regulation), we assert that fostering the engagement and positive growth required for adaptive expertise necessitates a holistic educational approach. This approach requires us to consider both the psychological needs of the learner, and the interaction between ecological factors and these psychological needs. We present a dynamic systems simulation model that is based on key concepts from self-determination and self-regulation theory. The model links factors in the learning environment, or 'ecological factors,' to outcomes related to student learning. To demonstrate that the model simulates the observed behavior of the system, we compare model simulations with student motivation measures in three learning situations that were designed and implemented by the authors. The evidence highlights the dramatic influence of ecological factors: high and low intrinsic motivations in different situations, and strong correlations between students' motivational orientations and ecological factors. Comparison of the simulated and measured student responses illustrates the potential for the integrated use of systems dynamics and learning science to aid design of learning environments that foster student motivation, engagement, and learning.

Keywords: holistic; self-determination; self-regulation; adaptive expertise; moral, ethics; learning environment; learning

Part II

Contributions in: Simulators, Remote Laboratories, Modelling, Curriculum Design, Assessment, Prediction of Students' Performance, and Innovation

Nenad Jovanović, Dragan Marković, 930-937 SIMAS: A Web-Based Computer System Simulator
Dejan Živković and Ranko Popović

This paper describes the web-based educational computer system simulator SIMAS. The simulator allows one to enter and compile an assembly language program, as well as load and execute the resulting machine code. Machine instructions can be executed one at a time or in continuous mode. Currently, the executed instruction is highlighted in the computer memory and every phase of its execution is presented visually to the user. The simulator enables the user to visualize the whole execution process of an instruction and to

compare assembly and machine language instructions side-by-side. The software package is written in Java as an applet and thus can be run from within any Java-enabled web browser.

Keywords: simulation; visualization; computer system organization; distance learning

Gonzalo Farias, Karl-Erik Årzén, 938–949 Teaching Embedded Control Systems
Anton Cervin, Sebastián Dormido and Francisco Esquembre

This paper introduces a novel approach to building virtual laboratories of embedded control systems using TrueTime and Easy Java Simulations. TrueTime is a freeware MATLAB/Simulink based tool commonly used to simulate embedded control systems. Easy Java Simulations is a popular authoring tool that facilitates the creation of pedagogical simulations. According to the proposed approach, authors use TrueTime to develop the simulation of an embedded control system and then move to Easy Java Simulations to link the system to a sophisticated graphical user interface that provides the visualization and user interaction of the virtual lab required for pedagogical purposes. The combination of these two tools conforms a powerful, yet simple, approach to the creation of effective pedagogic simulation of real-time control systems.

Keywords: control education; real-time; embedded control systems; virtual labs; TrueTime; EJS

Zhou Rui, Zhou Qingguo, 950–962 An Open Source and Network-based Remote Laboratory for Embedded Systems
Cheng Guanghui, Wang Baojun, Li Lian and Nicholas McGuire

The engineering education for embedded systems requires a suitable environment for practices and experiments. This kind of environment usually consists of a lot of hardware and software, so there is a pressing need to organize and manage all resources in a proper way to enable convenient access. In this paper, we present the design and implementation of a remote laboratory, aiming at the engineering education for embedded systems. This remote laboratory is built based on open source software and network technologies. It enables teachers to organize theoretical and practical contents in an easy way and students to communicate with teachers and take practical operations conveniently. The core of this remote laboratory is for students to learn in groups or by individual with the related resources as the interactive medium to guide, prompt and assist the learning and training procedure. With this environment, students can be located remotely while access real hardware devices easily. Meanwhile, it keeps the embedded development setup as a whole in good maintenance.

Keywords: remote laboratory; embedded systems; open source; network-based

Amir Aghakouchak and Emad Habib 963–973 Application of a Conceptual Hydrologic Model in Teaching Hydrologic Processes

In this study, a hands-on modeling tool is developed for students in civil engineering and earth science disciplines to help them learn the fundamentals of hydrologic processes and basic concepts of model calibration and sensitivity analysis, and practice conceptual thinking in solving and analysis of engineering problems. This modeling tool aims to provide an interdisciplinary application-oriented learning environment that introduces the hydrologic phenomena through the use of a simplified conceptual hydrologic model. The modeling tool was introduced in an upper-level civil engineering course and students were asked to submit their feedback before and after using the modeling tool through the Student Assessment of Learning Gains (SALG) online system to gauge improvement in their learning. The SALG report showed that the hands-on approach significantly added to students' learning and provided them with better understanding of interconnected hydrologic processes. Furthermore, students gained knowledge in areas that are not commonly taught in hydrology lectures (e.g. calibration, sensitivity analysis, etc). Based on the findings, some recommendations are given for further improvements in the use of hydrologic models as interactive tools for teaching complex and interconnected hydrologic concepts and inspiring students towards postgraduate education or future professional career.

Keywords: hydrology education; hydrologic modeling; hands-on laboratory program; conceptual thinking; interdisciplinary application oriented learning environment

Salvador Perez Canto 974–984 Redesign of Syllabus and Evaluation Procedures to Improve University Teaching in Subjects Related to Industrial Engineering in the Context of the European Higher Education Area

A process of integration is currently taking place to adapt our methodologies to the new guidelines established by the European Higher Education Area (EHEA). This situation is profoundly changing the way that university subjects are taught. As a part of this, we have to modify the teaching–learning process in terms of syllabus, didactic procedures, evaluation methodologies, etc. The main focus of this paper is on how to restructure several subjects in Industrial Engineering. The chief goal is to improve the work of teachers. Several weaknesses have been detected and justify the need for measures to improve the efficiency of teaching and evaluation.

Keywords: syllabus; teaching–learning process; evaluation; industrial engineering; European Higher Education Area

J. Peláez Vara, J. Ruiz Calvo, 985–996 A Pilot Study on the Adaptation of Mechanical Technology Modules to the European Higher Education Area
J. V. Martín Fraile and F. J. Gómez Gil

As part of a Mechanical technology module taught at Burgos University, a pilot project is presented which aims at a smooth transition from a teaching-based system to a learning-based system. This changeover is justified by student procrastination and passivity and backed by recommendations from institutions and business organizations. The objectives of this research are defined in terms of greater effectiveness, measured by the quality of the grades, and greater efficiency of the process, measured by the percentage of students sitting the exam and by the percentage of students that successfully complete the module. It also aims to strengthen oral and written communication skills and teamwork. Lecture methods give way to a combination of lectures and cooperative and collaborative learning techniques, which entail designing objectives, working materials, timetables, and assessment procedures. The introduction of active learning methods led to an 8% increase in the percentage of students attending the exam, a 31% increase in the percentage of students successfully passing the module, and an increase of 0.55 points in the grades awarded to students. A survey gained insight into student satisfaction with educational methods and the way in which they reinforce oral and written communication skills and teamwork.

Keywords: cooperative learning; collaborative learning; participative lecture; education; teaching-learning; European Area for Higher Education EHEA

Rubén Fraile, Irina Argüelles, 997–1007 A Systematic Approach to the Pedagogic Design of Final Year Projects: Learning Outcomes, Supervision and Assessment
Juan C. González, Juana M. Gutiérrez-Arriola, Juan I. Godino-Llorente, César Benavente, Lui Arriero and David Osés

Final Year Projects (FYPs) are nowadays relevant elements of university studies leading to several kinds of degrees. However, according to literature, most often the educational purposes of FYPs and their assessment procedures and criteria remain unspecified. This fact usually affects student performance and, consequently, it negatively nuances the educational aim of the FYP. Within this paper, the authors report on an effort to define a pedagogic design for final year projects in engineering university studies. This design includes a definition of the expected learning outcomes, a supervision scheme for final year projects and an assessment process. The definition of the expected learning outcomes has been made based on competences. Such a definition has served as a basis for designing a supervision process coherent with the expected educational outcomes. The competence-based definition of the educational outcomes

has also been used as a reference for designing the assessment system. Crucial aspects of this systematic approach are the competence-based definition of educational outcomes, the relation among educational outcomes, supervision process and assessment procedure and criteria and the methodology for mark weighting. Nevertheless, the applied methodology allows for easy adaptation of specific aspects to different contexts.

Keywords: final year projects; curricular design; assessment criteria

Shaobo Huang and Ning Fang 1008–1017 Prediction of Student Academic Performance in an Engineering Dynamics Course: Development and Validation of Multivariate Regression Models

The present study aims to develop a validated set of multivariate regression models to predict student academic performance in Engineering Dynamics—a high-enrollment, high-impact, and core engineering course. The models include eight predictor/independent variables that take into account student achievement before taking the course and student learning progression and achievement while taking the course. A total of 1,674 data points were collected from 186 undergraduate engineering students in two semesters. Four multivariate regression models were generated using different sample sizes of training datasets. The models were evaluated, validated, and compared using multiple criteria including R-square values, shrinkage, and prediction accuracy. The results show that the developed regression models have excellent predictability with 87–91% of the average prediction accuracy, and they have moderate predictability (46–66%) to generate good predictions (a good prediction is defined as a prediction that results in less than 10% of prediction error).

Keywords: multivariate regression; student academic performance; prediction accuracy; engineering dynamics

R. Scott Evans, Luz-Cristal S. Glangchai and Steven P. Nichols 1018–1026 Seeding and Harvesting the Innovation Gap: Linking Technology to Social and Market Needs

The Technology Innovation Mapping (TIM) Tool assists commercialization efforts and students studying product development and technology commercialization by linking the features of a technology to specific social needs (a term in broad perspective that includes technology commercialization used both for profit and not-for-profit applications), thus addressing the innovation gap between laboratory research and business incubators. This paper further develops the methodology; it summarizes the TIM Tool method and expands upon the TIM Tool to better capture the commercialization process for innovative technologies. The paper uses the application of a nano-scale drug delivery technology (advanced by a graduate student team) as a technology commercialization example.

Keywords: technology commercialization; innovation; function mapping