A project-based learning approach for a first-year engineering course

Jaime Núñez S.
Universidad Técnica Federico Santa María, Santiago, Chile, jaime.nunez@usm.cl

Sheila Lascano F.
Universidad Técnica Federico Santa María, Santiago, Chile, sheila.lascano@usm.cl

Iván E. Esparragoza
Penn State Brandywine, Media, PA, USA, iee1@psu.edu

ABSTRACT

The incorporation of professional competencies in the curriculum that complement the technical profile of engineers is a global trend in education. Therefore, exposing engineering students to experiences and learning environments that foster the development of professional skills as part of their formal education from the very beginning and in a consistent and effective manner must be a main task of every engineering program. The Introduction to Engineering course is a great opportunity to expose the engineering students to scenarios to start developing professional skills. However, it is evident the lack of maturity of freshmen students to address challenges and engineering projects. The aim of this work is to propose a structure for an introductory course in engineering based on competencies that provides a framework for engineering practice. This paper describes the learning areas, competencies, learning outcomes and activities that will contribute to develop the knowledge, skills and attitudes that are crucial to prepare students to face tougher challenges. The proposed framework allows students to engage in engineering practice individually and as a team through the design and construction of a product, a process or a system. This work also involves future works on the assessment of skills for teamwork, social consciousness, ethics and project planning.

Keywords: competencies, engineering education, introductory courses, active learning.

1. INTRODUCTION

Over the past 25 years, many in industry, government, and university programs have addressed the need for reform of engineering education, to educate world-class engineers who possess technical expertise and professional skills, often by stating the desired outcomes in terms of attributes of engineering graduates, i.e. *what the engineers do?*. The modern engineers will be prepared to use knowledge, skills and attitudes to design competitive products, systems, components, or processes to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability, and must be able to identify, formulate, and solve engineering problems (ABET, 2011). However, with the globalization phenomena, engineers are being challenged to design and develop, in a timely manner, new products that will impact a global market (Esparragoza & Devon, 2005). Therefore, the challenge is educate global engineers with an ability to function on multidisciplinary teams and multi-cultural teams, to work in multi-national corporations, an understanding of professional and ethical responsibility, an ability to communicate effectively, the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context, a recognition of the need for, and an ability to engage in life-long learning, a knowledge of contemporary issues, an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice, an ability to think both critically and creatively—independently and cooperatively, and ability and self-confidence to adapt to rapid or major change (ABET, 2011; Esparragoza, 2005).

The new global trend in education is the incorporation of professional competencies in the curriculum that complement the technical profile of engineers. Therefore, exposing the engineering students to experiences and learning environments that foster the development of professional skills as part of their formal education from the very beginning and in a consistent and effective manner must be a main task of every engineering program. The introductory course is an early engineering course that aims to establish the framework in which engineers work and contribute to society. It serves to stimulate students' interest in, and strengthen their motivation for the field of engineering. Students usually elect engineering programs because they want to create and build. Introductory courses can take advantage of on this interest. In addition, the introduction to engineering course provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills. This framework is a broad outline of the tasks and responsibilities of an engineer and the use of disciplinary knowledge in executing those tasks. Students engage in the practice of engineering through problem solving and simple design exercises, individually and in teams. The course also includes personal and interpersonal knowledge, skills, and attitudes that are essential at the start of a program to prepare students for more advanced product, process, and system building experiences (Crawley, Malmqvist, Östlund, & Brodeur, 2007). However, the complexity of this task is defining the learning objectives, expected competencies outcomes and activities to develop the appropriate assessment tools and evaluation. The aim of this paper is to present the framework for a project-based introduction engineering course based on competencies. This work is the first phase of a bigger project that includes the development of the assessment tools and the final deployment and test of those instruments.

2. RATIONALE: BACKGROUND AND MOTIVATION

This work is part of the tasks assumed by the Department of Mechanical Engineering at Technical University Federico Santa Maria (UTFSM) in Chile with the aim of ensuring the competitiveness and quality of its engineering program in response to the assessment conducted in 2011 by the National Commission on Accreditation. Among the objectives set by the program, those of particular relevance for this work are: (a) to facilitate project-based learning (PBL) experiences; (b) the design of an integrated curriculum based in competencies to develop technical and professional skills.

This work proposes to incorporate the project-based learning (PBL) approach in a first year course in the mechanical engineering curriculum at UTFSM. This approach calls for the need of formal assessment tools for both specific learning objectives in the introductory course, as well as transverse competencies to be developed to contribute to the formation of the profile of mechanical engineers that will be described.

3. EDUCATIONAL APPROACH: PROJECT-BASED LEARNING (PBL) AND COMPETENCIES

As it was described before, industry, government, and university programs have addressed the need for reform of engineering education to prepare world class engineers. Engineering program accreditation agencies such as ABET have considered the demands of the industry and have included this in their Professional Outcomes (ABET, 2011). Programs like CDIO have incorporated this topics in this structure (Crawley et al., 2007). Meanwhile, the ASEE Engineering Deans Council Pipeline Implementation Committee considered particularly important, among the task for engineering education, "develop or expand… first-year entry programs that should introduce students …to the spectrum of opportunities in engineering and provide them with engineering experiences."(Bickart, 1991).

Therefore, universities need to offer an interdisciplinary curriculum that combines theory and practice to engage students in authentic real-world tasks and to develop their skills in problem solving (Macías-Guarasa, Montero, San-Segundo, Araujo, & Nieto-Taladriz, 2006). The engineering programs should provide their students, as early as possible, academic experiences to promote the development of professional skills as part of their training. One way this can be achieved is exposing to first year engineering students to learning experiences through design projects in which students develop engineering jobs in teams to solve an engineering problem. Project-based learning (PBL), a student-centered teaching approach, enables students to integrate their knowledge, skills, values, and attitudes and to construct knowledge through a variety of learning experiences (Maskell & Grabau, 1998). This methodology is based on the idea that a problem or a question, guide learning activities for the construction of a particular device in a real context (Panikolaou & Boubouka, 2010). In this process, students deal with interdisciplinary issues as well as pursue solutions to a problem by asking and refining questions, debating ideas, plan design, making predictions, collecting and analyzing information, drawing conclusions, creating artifacts or products and communicating their findings to other students (Blumenfeld et al., 1991; Macías-Guarasa et al., 2006). Therefore, the PBL promotes the develop of technical knowledge and professional competencies (Helle, Tynjala, & Olkinuora, 2006) engaging students in authentic real-world tasks. This aspect is important because the students usually choose engineering programs to create and build. The introductory courses provide an early start to the development of the personal and interpersonal skills, and product, process, and system building skills. This role in an integrated curriculum could be illustrated by mean metaphor of building a vault (Figure 1). The introductory course is similar to centering in that it gives students a quick insight into engineering practice and the roles of engineers and provides a set of early authentic personal experiences that motivate the need for disciplinary content, and allow early fundamentals to be more deeply understood (Crawley et al., 2007).

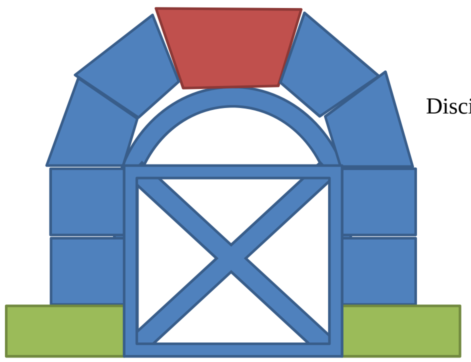


Figure 1: Metaphor of an integrated curriculum structure (Crawley et al., 2007).

Introduction to Engineering courses and those of similar names and purposes have been identified (Dini, Musiak, & Grabiec, 1992; Gunn, 1996; Hoit & Ohland, 1998; Knickle, 1996; McDonald, 1995; Milano, Parker, & Pincus, 1996; R. B. Landis, 2007; Woolston, Shook, & Wilson, 1996). However, when this introductory courses include a design-implement experience of some kind that is carried out by student teams, this experience contribute to development of professional skills. Some evidences courses supports the idea that design/implement projects improve students' comfort level working on technical problems that have no clear solutions (West, 1991). Moreover, students are able to demonstrate an understanding of how to design and build a device from an unidentified assortment of parts (Newman & Amir, 2001).

Hence, the evaluation of this design/implement projects is also an important aspect. In most engineering programs, learning assessment focuses on disciplinary content. However, an equal emphasis needs to be placed on assessing the personal and interpersonal skills, and design/building skills that are integrated into the curriculum. Figure 2 illustrates a process of learning assessment that can be implemented in any educational program. Assessment of student learning begins with the specification of learning outcomes that students will achieve as a result of instruction and related learning experiences and in some cases use a single assessment method, which will not suffice to gather evidence of the broad range of learning outcomes (Crawley et al., 2007).

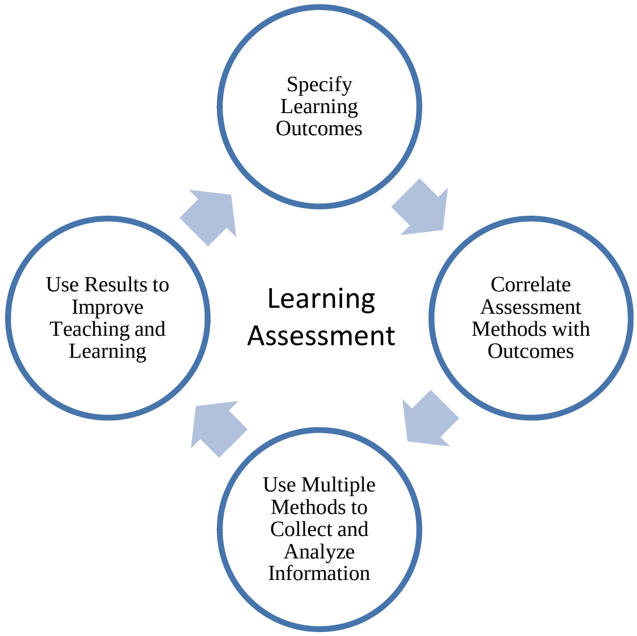


Figure 2: Learning assessment process in perspective with global engineering education (Crawley et al., 2007).

4. Course Description

The course considered in this work is part of the first semester of the curriculum of Mechanical Engineering. This course is traditionally used as an opportunity for students to learn about the history of the university and its founder so student can identify with the values and vision of the institution. The aim of this course is to provide an overview of the work performed by mechanical engineers, the responsibilities they face and their contribution to the society. This goal is reached by highlighting the knowledge domain and professional skills required to be successful in the professional practice.

This introductory course aims to stimulate students' interest and strengthen their motivation for the field of mechanical engineering, providing an early start on the development of skills, both personal and interpersonal, necessary for the development and effective practice of competencies related to the design, implementation and operation of products, processes and systems.

4.1 Course Objectives, Outcomes and Competencies

In this section the learning objectives, outcomes and competencies defined for this course are presented. These elements will guide the content of the course and the design of the learning activities including the design project embedded in this course as part of the PBL approach used in this course. Also includes correspondence with CDIO Syllabus v2.0 June 2011 (Crawley, Lucas, Malmqvist, & Brodeur, 2011) in order to demonstrate alignment with these criteria.

4.1.1 Learning Outcomes

At the conclusion of the course, students should be able to:

- CO.1 Distinguish, in the context of the University as an organization, cultural traits, values and history of the organization and its founder.
- CO.2 Recognize the technical, social, environmental and ethical context of the professional practice of mechanical engineering.
- CO.3 Work in a team in the solution of an engineering challenge

CO.4 Design and build a mobile mechanical system that uses a clean energy source, using methodologies, techniques and basic engineering principles

CO.5 Communicate and summarize effectively, orally, graphically and in writing, their ideas, insights and results through reports and presentations to various audiences and levels of evaluation.

4.1.2 EXPECTED OUTCOMES

EO.1 Search printed literature and online information relevant to the problem or challenge face.

EO.2 Manages time and resources efficiently to tackle the problem or challenge faced.

EO.3 Demonstrates critical thinking towards information, ideas and knowledge being discovered.

EO.4 Act with ethics, integrity and social responsibility in all the course and teamwork activities.

EO.5 Work well in the team by inquiring, listening and dialoguing, establishing negotiation, compromising and resolving conflicts within his team.

EO.6 Communicate effectively their ideas and results by means of reports and oral presentations using technology and multimedia.

EO.7 Recognize the competencies, roles and responsibilities of the engineer.

EO.8 Recognize the impact of engineering on society and the environment when anal solving an engineering challenge.

EO.9 Understand the needs, constraints and goals of the design and construction of the project given in the course.

EO.10 Use the design process in the solution of the engineering design challenge given in the course.

EO.11 Apply suitable manufacturing processes at a basic level to realize a prototype.

EO.12 Realize tests, verification and validation of the prototype built.

EO.13 Evaluate the performance of the prototype built in the final competition of the course

4.1.3 ENGINEERING CORE COMPETENCIES DOMAINS AND COMPETENCES

"Design, Development and Construction Machinery, Equipment and Industrial Complexes"

EC.1 Demonstrate the ability to design, plan and develop energy systems, production systems, machinery and equipment, goods of intermediate consumption, with the highest quality standards, under considerations of respect for people, and existing environmental legislation.

"Design and Development of Production Process and Transformation of Energy"

EC.2 Demonstrate the ability to conduct and promote research and development of experiments, enabling innovation, incorporation or development of new technologies in the field of specialty.

"Senior Technical Direction and Management of Technological Enterprises"

EC.3 Demonstrate the ability to use the tools for managing, monitoring and optimizing the use of human, material and financial dependents.

EC.4 Demonstrate the ability to use scientific knowledge and technological expertise in mechanical engineering for the design, development, implementation and operation of processes and products.

4.1.4 CONTENT: TECHNICAL AND PROFESSIONAL KNOWLEDGE, SKILLS, ATTITUDE

This section presents the proposed KSA in the *CDIO Syllabus v2.0 June 2011* in order to demonstrate alignment with the expected outcomes of the course.

A. PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES

A1. Survey of Print and Electronic Literature (2.2.2)

A2. Trade-offs, Judgment and Balance in Resolution (2.3.4)

A3. Initiative and the Willingness to Make Decisions in the Face of Uncertainty (2.4.1)

A4. Perseverance, Urgency and Will to Deliver, Resourcefulness and Flexibility (2.4.2)

A5. Critical Thinking (2.4.4)

A6. Time and Resource Management (2.4.7)

A7. Ethics, Integrity and Social Responsibility (2.5.1)

A8. Professional Behavior (2.5.2)
A9. Team Operation (3.1.2)
A10. Written Communication (3.2.3)
A11. Electronic/Multimedia Communication (3.2.4)
A12. Graphical Communication (3.2.5)
A13. Oral Presentation (3.2.6)
A14. Inquiry, Listening and Dialog (3.2.7)
A15. Negotiation, Compromise and Conflict Resolution (3.2.8)

B. CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT
B1 Roles and Responsibility of Engineers (4.1.1)
B2 The Impact of Engineering on Society and the Environment (4.1.2)
B3 Understanding Needs and Setting Goals (4.3.1)
B4 Defining Function, Concept and Architecture (4.3.2)
B5 System Engineering, Modeling and Interfaces (4.3.3)
B6 Development Project Management (4.3.4)
B7 The Design Process Phasing and Approaches (4.4.2)
B8 Hardware Manufacturing Process (4.5.2)
B9 Test, Verification, Validation, and Certification (4.5.5)
B10 Implementation Management (4.5.6)
B11 Operations Management (4.6.6)
B12 Planning and Managing a Project to Completion (4.7.6)
B13 Implementation and Operation – the Creation and Operation of the Goods and Services that will Deliver Value (4.7.10)

5. PROJECT DESCRIPTION

The project considered for this course is related to the use of energy efficient transportation system subjected to certain constraints. Students are challenged to: (a) solve this design project in groups; (b) use the design process to develop concepts and select the best alternative; (c) document the process; (d) report de results in a written report and oral presentation. The details of the project as is given to the students are described below.

PROJECT "TURBOMEC"
The challenge:
Design and build a mobile mechanical system "*Turbomec*" capable of carrying a kilogram of sand in a straight line on a flat floor, as far as possible. The energy to be used will be a *pressure battery* formed by a plastic beverage bottle of 1.5 liters with water and pressurized air at 5 bars.

Restrictions:
- The materials used for the construction of the vehicle, should be only waste materials (recycled).
- The components included in the system *Turbomec* should not be used for the same purposes for which they were originally designed (parts of toys and other artifacts).
- For propulsion, shall be used only potential energy contained in the *pressure battery* (plastic bottle of 1.5 liters), water and pressurized air to 5-bars (~ 70 psi).
- The displacement must be made by the traction wheel and the air free jet should not be used.
- The structure and the transmission system must also be designed to carry the actual mass of the device, including the *pressure battery*, a closed cylindrical vessel 95 mm in diameter and 100 mm in height where the mass of 1 kg of sand is contained.

Project Stages and Results.

The stages followed by the students in the completion of the *Turbomec* project, are summarized in Table 1. The images showed provide evidence on project team's work.

Table 1: Development and results of design & implement using project-based learning approach for a first-year engineering course.

Stage 1: Organization and Planning

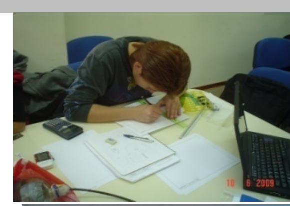
1. Identification and analysis of the proposed problem.
2. Systemic analysis of the artifact (concept map).
3. Identify potential risks and measures to take.
4. Vision, Mission and Motto Team. Corporate Image
5. Organizational procedures and standards and project team roles
6. Planning and assigning work (Gantt chart first version)

Stage 2: Analysis and Functional Modeling

1. Identify, classify and prioritize tasks, set restrictions.
2. Functional Analysis Diagram.
3. Draft formal Turbomec dimensional system
4. Preliminary analysis of functional stresses
5. Requirements estimated special materials and supplies.
6. Work planning (Gantt chart final version)

Stage 3: Design Turbomec Systems.

1. Design of energy transfer and adaptation system.
2. Design of transmission and suspension system.
3. Structural design of the chassis.
4. Manufacturing Process Development Sheets.
5. Quality assurance (FMEA: Failure Mode and Effects Analysis)
6. Final draft formal concept (shape and appearance) of the artifact.



Stage 4: Construction and Prototype Test

1. Manufacture of parts and components.
2. Implementation of the prototype
3. Testing and Verification
4. In class competition

5.1.1 MAPPING CONTENT, PROJECT, COMPETENCIES AND LEARNING OBJECTS

A mapping of the course content and learning activities in the introductory course with the expected outcomes, competencies domains and curse objectives are showed in Table 2. This mapping helps to define the content of the course and activities to satisfy the expected learning outcomes and competencies. This mapping serves also for the development of appropriate tools for assessment of the course.

Table 2: Framework of a first year engineering course based in competencies using active learning method.

Course content	**Learning Experiences**	**Learning outcomes**	**Expected outcomes**	**Competences Domains**	**Tech. and Professional KSA (CDIO)**
Cultural Induction UTFSM	Lecture (definition and characteristics of organizational culture). Teamwork research on culture and values of the institution. Group and individual reflection on culture and values of the institution	CO.1; CO.5	EO.1; EO.2; EO.3; EO.4; EO. 5; EO.5	EC.1	A.1; A.5; A.6; A.7; A.9; A.10; A.14
Competencies for the engineer of the 21st century	Lecture (definitions of skills and accreditation criteria of competencies). Teamwork research on professional skills of the mechanical engineer. Group oral presentation on professional skills of the mechanical engineer represented in a concept map.	CO.2; CO.5	EO.1; EO.2; EO.3; EO.4; EO. 5; EO.5; EO.6; EO.7; EO.8	EC.1; EC.2	A.1; A.5; A.6; A.7; A.9; A.10; A.11; A.12; A.13; B1; B2
Practice Mechanical Engineering	Conduct an interview to a Mechanical Engineer. Teamwork presentation about the interview results and conclusions Group and individual reflection on mechanical engineer professional skills	CO.2; CO.5	EO.1; EO.2; EO.3; EO.4; EO. 5; EO.5; EO.6; EO.7; EO.8	EC.1; EC.2	A.1; A.5; A.6; A.7; A.8; A.9; A.10; A.11; A.12; A.13; B1; B2
Project *TURBOMEC*	Lectures (definition, problem solving, design process, design objectives, functional analysis, conceptual design) Project: *TURBOMEC*	CO.3; CO.4; CO.5	EO.1; EO.2; EO.3; EO.4; EO. 5; EO.6; EO.9; EO.10; EO.11; EO.12; EO.13	EC.1; EC.2; EC.3; EC.4	A.1; A.2; A.3; A.4; A.5; A.6; A.7; A.8; A.9; A.10; A.11; A.12; A.13; B.1; B.2; B.3; B.4; B.5; B.6; B.7; B.8; B.9; B.10; B.11; B.12; B.13

6. Conclusions And Future Work

There are in the literature different experiences of applying active methods, PBL, in introductory engineering courses. This paper uses the authors' experiences in implementing these methodologies. In particular those activities developed in the Department of Mechanical Engineering UTFSM-Chile since 2009.

A first-year engineering course based on competencies, which aims to develop an interconnected set of knowledge, skills and attitudes, requires a continuous evaluation and improvement process in order to increase the impact on students and involves a systematic qualification for faculty in order to extend these PBL methodologies to other courses.

Future work will establish the following challenges:

- Design, validate and apply assessment tools for achieving learning outcomes, incorporating a holistic approach in the evaluation, in order to support the use of PBL methodologies.
- Train instructors so they can develop the skills and personal and interpersonal attitudes necessaries to incorporate this methodology in the classroom and the competencies to increase the effectiveness of PBL methodologies.
- Develop a plan to change paradigms in engineering education and promote classroom practices towards active learning that facilitate the development of skills and professional attitudes, personal and interpersonal, across the mechanical engineering at UTFSM.

References

ABET. (2011). 2012-2013 Criteria for Accrediting Engineering Programs. USA: ABET.

Bickart, T. A. (1991). Gateway to Pluralism: Recruitment and Retention. Engineering Education, 419.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. Educational Psychologist, 26(369-398).

Crawley, E. F., Lucas, W. A., Malmqvist, J., & Brodeur, D. R. (2011, June 20 – 23, 2011). The CDIO Syllabus v2.0. An Updated Statement of Goals for Engineering Education. Paper presented at the 7 th International CDIO Conference, Technical University of Denmark, Copenhagen.

Crawley, E. F., Malmqvist, J., Östlund, S., & Brodeur, D. R. (2007). Rethinking Engineering Education. New York, NY: Springer Science+Business Media, LLC.

Dini, S., Musiak, R., & Grabiec, R. (1992). Helping Today’s Student Succeed in Engineering: A Freshman Orientation Course. Paper presented at the 1992 ASEE Annual Conference, Session 1253.

Esparragoza, I. E. (2005, 25-29 July 2005). International experience for freshman engineering students through multi-national global design projects. Paper presented at the Proceedings of the International Conference on Engineering Education ICEE-2005, Gliwice, Poland.

Esparragoza, I. E., & Devon, R. (2005, 8-10 June 2005). Developing the global design curriculum in Latin America and the Caribbean through multi-national projects. Paper presented at the Proceedings of the 3rd Latin American and Caribbean Conference for Engineering and Technology, Cartagena, Colombia.

Gunn, C. J. (1996). Addressing the Freshman Need for an Engineering Experience. Paper presented at the ASEE Annual Conference, Session 2653.

Helle, L., Tynjala, P., & Olkinuora, E. (2006). Project-based learning in post-secondary education: Theory, practice, and rubber sling shots. Higher Education, 51, 287-314.

Hoit, M., & Ohland, M. (1998). The Impact of a Discipline-Based Introduction to Engineering Course on Improving Retention. Journal of Engineering Education.

Knickle, H. (1996). Foundations of Engineering—A First Year Course. Paper presented at the 1996 ASEE Annual Conference, Session 2653.

Macías-Guarasa, J., Montero, J. M., San-Segundo, R., Araujo, A., & Nieto-Taladriz, O. (2006). A project-based learning approach to design electronic systems curricula. . IEEE Transactions on Education, 49(3), 389-397.

Maskell, D. L., & Grabau, P. J. (1998). A multidisciplinary cooperative problem-based learning approach to embedded systems design. IEEE Transactions on Education, 41(2), 101-103.

McDonald, D. (1995). Enhancing the Recruitment and Retention of First-Year Students with Improved Career Selection Opportunities. Paper presented at the 1995 Frontiers in Education Conference, IEEE, Session 3a32.

Milano, G. B., Parker, R., & Pincus, G. (1996). A Freshman Design Experience: Retention and Motivation. Paper presented at the 1996 ASEE Annual Conference, Session 2553.

Newman, D. J., & Amir, A. R. (2001). Innovative First-Year Aerospace Design Course at MIT. Journal of Engineering Education, 90(3), 375-381.

Panikolaou, K., & Boubouka, M. (2010). Promoting Collaboration in a Project-Based E-Learning Context. JRTE, 43, 135-155.

R. B. Landis, R. B., , Discovery, Burbank, CA, 1995. (2007). Studying Engineering: A Roadmap to a Rewarding Career (3rd ed.). Los Angeles, CA: Discovery Press.

West, H. (1991). A Criticism of an Undergraduate Design Curriculum", Design Theory & Methodology,. ASME DE, 31, 7-12.

Woolston, D. C., Shook, K., & Wilson, J. (1996). Same Problem, Different Solutions: Attempts at Improving Retention in Engineering at a Research vs. A Teaching University. Paper presented at the 1996 Frontiers in Education Conference, IEEE, Session 3a31.

Authorization and Disclaimer