Innovation in engineer graduation

Danielle Miquilim

Universidade Paulista - UNIP

miquilim@hotmail.com

Marcia Terra da Silva

Universidade Paulista - UNIP

marcia.terra@uol.com.br

Abstract

This paper aims to display the key factors of innovative teaching in engineering graduation, utilizing as method a systematic bibliography revision through Web of Science platform. The researched articles quote as factors: flexible and interdisciplinary curriculum, use of pedagogical methodologies oriented towards the student, as well as learning processes.

Keywords: Innovation, Engineer, Graduation

INTRODUCTION

The concept of innovative university is related to different aspects that complement each other and involve from initiatives related to didactic teaching to the management of institutions.

Therefore, the innovative initiative should be pursued by the entire teaching and administrative staff, in order to meet the expectations of the students to this new and more connected profile, because they are not content with ready-made answers, but sharpen the technical and behavioral skills.

Innovation in contemporary society is one of the factors associated with social and economic development of the nations. Mota (2011) points out that the concept of innovation, in general, "is correlated with research and development (R&D), but distinct and broader, being necessarily associated with the application of knowledge."

The universities have always been considered key elements for economic development, in training, creation and transfer of knowledge. Their ability in academic education is unquestionable, and with the enhancement of knowledge resources, the universities analyze how much more they can do for the society in the creation of new knowledge, new technologies and new professional skills to increase productivity and to improve the capacity and regional development (Goldstein and Drucker, 2006).

It is possible to realize a considerable distance between the profiles proposed by the engineering educational institutions and the real needs of the labor market towards these engineers. The future engineer needs a more varied background that combines theory with practice and gives him ability to solve real-world problems (Grimoni et al. 2014).

With the market demand each time more complex, new engineering graduations try, since the start, to tune their curricula with the reality of the companies. In addition to good management with numbers, the innovative engineering universities are seeking to prepare future engineers for practical challenges with vision in the technological development.

The purpose of this article is to characterize the innovative education in engineering schools. And help the understanding of the teaching learning process of an innovative engineering university.

FLEXIBLE CURRICULUM MATRIX AND INTERDISCIPLINARITY

An ongoing concern when discussing curriculum in engineering is the flexibility and dynamism, due to the fast technological changes, societal needs and expectations of the society about the work of the engineer.

According to Christiansen (1992) the society expects that the engineering schools train professionals engaged in the society, aware of their responsibilities. Christiansen (1992) cites the curriculum proposal of the "Worcester Polytechnic Institute", of Massachusetts, USA, where there is a minimum of 30% of the credits in all periods for the humanities and social sciences disciplines.

Lopes et al. (1998) propose to form professionals critically linked to the labor market, to produce knowledge and handle with social issues. Sousa (1990) discusses the adequacy of the engineer to the market, not as a mere process of submission to the immediate needs of the labor market, but as a critical and innovative process. This generalist engineer, with a strong focus on basic science, is required to the development of technologies and participates creatively in new areas, as well as having more ability to work in multidisciplinary teams (Sousa (1997).

This profile implies curriculum features that go far beyond the minimum curriculum, and implies pedagogy focused on the interaction between students versus teachers, allowing practice attitudes, skills and proposed abilities (Sousa 2000).

The curriculum flexibility aims to continuously adapt the curriculum on changes in technology and in the society needs, bringing updated curricula. This goal can be achieved by maintaining a high margin of elective disciplines in the curriculum, as well as free choice courses. One must define a minimum content required for a curriculum in compulsory disciplines and leave a good margin of knowledge, attitudes and skills to be exercised in optional and free choice courses (Dertouzos 1992).

Therefore, the interdisciplinarity observed in engineering schools can also be achieved by flexible curriculum that allows students from an area of engineering to take courses from another area, by choosing elective disciplines. In addition, the free choice disciplines allow a much more radical interdisciplinarity, because the engineering student can take courses from any other college degree at the same university (Lopes 1998).

In choosing between specialized training and general education, today the choice of general education prevails. The same above problem of the fast evolution of knowledge in engineering prevents the specialization, because the greater the specialization, the faster the obsolescence of knowledge. A general education will allow greater basis for interdisciplinary works in new areas, including allowing migrations among areas, as it currently happens in the lives of the engineers.

TEACHING METHODS

In the exact sciences schools there is often the departmentalization, which is the division of the various areas of knowledge in different contents that promotes a segmentation of the various areas of education, which does not contribute to the teaching learning process.

As a result, new methods of learning have become an object of study and research for many educational institutions around the world. Engineering schools seek with these new methods development of attributes that contributes to a good performance in their future employments.

These attributes can be classified into three categories (Bailey and Bennett 1996; Vasilca 1994; Von Linsingen et al. 1999): (a) knowledge: the domain of the fundamental principles of engineering (science and technology), as well as expertise in computing, business administration, profits, impact of technology on the environment and on people etc.; (b) skills: project development, problems analysis, synthesis of solutions referenced to practices in use, communication and interpersonal skills, orientation to work in teams as a leader and led, resource management, systemic vision etc.; (c) attitudes: ethics, integrity and responsibility towards the society and the profession, concern for the environment, initiative, entrepreneurship, adaptability to constant changes, willingness to look for experts when necessary, motivation and interest in active and continuing learning throughout their careers, creativity etc.

The question that always arises to engineering universities and departments is how to incorporate the teachers and the students of a growing knowledge and how to develop the skills and attitudes necessary for good professional performance without overloading the curriculum or extend the courses. Some authors, such as Zabala (1998), propose to work these three categories simultaneously in the classroom. One way to achieve this would be through the use of teaching methods such as PBL - Problem Based Learning (Savin-Baden 2000), by offering the students a way to acquire knowledge and develop the skills and attitudes valued in the working life and in the school context in an integrated manner.

PROBLEM BASED LEARNING (PBL)

PBL is a methodological proposal characterized by the use of real-world problems to encourage students to develop critical thinking and problem-solving skills and acquire knowledge of the essential concepts of the area in question. PBL originated in 1969 at McMaster University, Canada, for medicine study, but it is possible to find examples of implementation of PBL in the entire educational system, such as in business administration education (Stinson and Milter, 1996), and engineering (Hadgraft and Prpic, 1999; Woods, 1996, 2000).

Many of the guiding elements of PBL have already been selected previously by educators and educational researchers around the world, such as Ausubel, Bruner, Dewey, Piaget and Rogers (Dochy et al., 2003). In Brazil, some of its principles can be found, although they were later neglected, in the intentions of the founders of the University of Sao Paulo in the 30s (Masetto 2003).

PBL can be considered innovative as it can incorporate and integrate various concepts of educational theory and implement them in the form of a consistent set of activities. Gijselaers (1996) believes that PBL has three fundamental principles of learning: (1) learning is a constructive and not receptive process - knowledge is structured in networks of concepts related to each other, and new concepts are learned as they are related to existing networks, being therefore, important to activate the prior knowledge of the students about the issue at hand in order to achieve the learning of new concepts related to it; (2) metacognition affects learning - skills such as goal setting (what will I do?), selection strategies (how will I do?), and evaluation of results (did it work?), are considered essential to learning; and (3) contextual and social factors influence learning - the context in which teaching takes place promotes or inhibits learning.

The main difference between PBL and other teaching learning methods is the fact that the problem drives and motivates learning. One problem with this approach is open-ended, that is, it does not contain a single correct solution, but one (or more) best solutions, given the constraints imposed by the problem itself or by the learning context in which it appears, such as time, resources etc (Barrows 2001). Moreover, the problem in PBL promotes the integration of the concepts and skills necessary for the solution, which requires a troubleshooting process and the commitment to independent learning by the teams (Hadgraft and Prpic, 1999).

Although PBL is implemented throughout the course, guided by a set of issues that form the backbone of its curriculum, it can be found successful application reports of PBL as a partial educational strategy, that is, in parts of courses (Stepien and Gallagher, 1998), or in isolated disciplines within a conventional curriculum (Wilkerson and Gijselaers, 1996).

THE ROLE OF THE TEACHER AND OF THE STUDENTS

PBL implies different challenges for students and teachers, compared to the ones associated with formal education. According to Gijselaers (1996) the primary role of the teacher in this methodology is to guide the groups, giving support to the interaction among the students.

On the other hand, the students must take responsibility for their learning by designing it to meet their individual needs and career aspirations. Barrows (2001) believes that the delegation of responsibility for learning (empowerment) teaches the students how to learn for the whole life – an extremely useful skill, since it is believed that much of the knowledge acquired in school will be outdated when the students are starting their working lives.

To be responsible for their own learning implies that the students shall perform the following eight tasks: (1) explore the problem, raise hypotheses, identify and develop the research questions; (2) try to solve the problem with what is known, noting the relevance of the current knowledge; (3) identify what is not known and what one needs to know to solve the problem; (4) prioritize learning needs, set goals and learning objectives and allocate resources in order to know what, how much and when it is expected and, for the team, determine which tasks each one will make; (5) plan, delegate responsibilities for self-study team; (6) share the new knowledge effectively so that all members learn the knowledge surveyed by the team; (7) apply the knowledge to solve the problem; (8) evaluate the new knowledge, the problem solving and the effectiveness of the procedure used and reflect on the process (Barrows, 2001; Samford University, 2000; Woods 2000).

It is important to point that, in despite of being based on learning through problem solving, PBL is not merely a technique for solving problems. Troubleshooting techniques are fundamental in this educational approach, but PBL is not just this. Hadgraft and Prpic (1999) emphasize that the main activity of the students in the PBL educational environment is learning – identifying what they need to know, investigating, teaching each other and applying new knowledge - and not the mere task completion. In this methodology, the knowledge built in the search for the problems solution, and the skills and attitudes developed in this process are more relevant than the solution *per se*.

METHODOLOGY

We used the electronic Web of Science database to select the articles that should meet the following inclusion criteria: (1) in the title name: innovation, higher education, and (2) keywords: innovation, graduation, higher education and engineering. An initial analysis was performed based on the titles of the manuscripts and in the abstracts of all articles that met the inclusion criteria or did not allow to make sure that they should be excluded. After analyzing the abstracts, we examined all selected articles.

After defining which papers should be included based on the electronic search, we made a research conducted by the name of the first author of the selected articles, in order to find other publications that met the inclusion criteria. Some non-indexed or recent indexed journals were examined manually: Journal of Engineering Education, European Journal of Engineering Education, Journal of Professional Issues in Engineering Education and Practice and International Journal of Engineering Education.

We selected and analyzed sixty articles that presented a wide variety of subjects. Thirty-two articles analyzed the innovation with some factors that lead to the matter on higher education.

RESULTS AND DISCUSSION

We analyzed the thirty-two articles, and from them, we selected sixteen articles that were presented in Table 1 by their authors, the year and the concepts that each author has on an innovative engineering course.

Table 1 - Selected Results

Author	Year	Concept
CHRISTIANSEN	1992	The society expects that the engineering schools train professionals engaged in society, aware of their responsibilities.
DERTOUZOS	1992	The curriculum flexibility aims to continuously adapt the curriculum to the changes in technology and the needs of the society, bringing the maintenance of updated curricula.

GIJSELAERS	1996	PBL has three fundamental principles of learning: (1) learning is a constructive and not receptive process; (2) metacognition affects learning (objectives, strategies and evaluation of the results); (3) contextual and social factors influence learning.
GIJSELAERS	1996	The primary role of the teacher is to guide the groups, giving support to the interaction among the students so that it is productive, and helping the students to identify the knowledge to solve the problem.
SOUSA	1997	The engineer must have a general education, which enables him to work on innovations in new areas, and to keep up with technological changes.
LOPES	1998	The interdisciplinarity observed in engineering schools can also be achieved by the curriculum flexibility that allows the students from an area of engineering to take courses from another area, by choosing elective courses.
ZABALA	1998	The importance of incorporating the teachers and the students of a growing knowledge and develop the skills and attitudes necessary for good professional performance without overloading the curriculum or extend the courses.
HADGRAFT and PRPIC	1999	The PBL teaching method promotes the integration of the concepts and skills required for the solution, which requires a troubleshooting process and the commitment to independent learning by the teams.
HADGRAFT and PRPIC	1999	PBL is a more effective means of learning where the students identify what they need to know, investigate, teach each other and apply new knowledge - and not the mere task completion.
SAVIN-BADEN	2000	PBL offers the students a means to acquire knowledge and develop the skills and attitudes valued in working life and in the school context in an integrated manner, that is, without the need for disciplines or courses specially designed for this purpose.
BARROWS	2001	The delegation of responsibility for learning (empowerment) teaches the students how to learn for life - an extremely useful skill since it is believed that much of the knowledge acquired in school is outdated when the students are starting their working lives, particularly in the field of applied sciences such as engineering.
BARROWS	2001	The main difference between PBL and other teaching learning methods, such as active learning, in teams or focused on students, is the fact that the problem drives and motivates learning.
MASETTO	2003	Place the student in contact with the professional reality since the first year; overcome the theoretical requirements for starting to practice; acquire knowledge in a way not necessarily logical and sequential; build networking knowledge, not linear; make the students responsible for their professional development and ethical behavior in relation to colleagues, teachers and the society.

GOLDSTEIN and DRUCKER	2006	The universities have always been considered key elements for economic development, training, creation and transfer of knowledge. Their ability in academic education is incontestable, and with the enhancement of knowledge resources, these authors analyze how much more they can do for the society in the creation of new knowledge, new technology, and new professional skills to increase productivity and to improve the capacity and regional development.
MOTA	2011	The concept of innovation in general "is correlated with research and development (R&D), but distinct and broader, being necessarily associated with the application of knowledge".
GRIMONI	2014	The future engineer needs a more varied background that combines theory with practice and gives him ability to solve real world problems.

The analysis of the collected articles shows: (1) the existence of the need for innovative universities in engineering, which requires changes that permeate the learning process of teachers and students, looking for tuning the curricula because of the changes taking place in the labor market and (2) there is not a model featuring an innovative university in engineering, but disclosed proposals, in powdered form, showing a fragmented view on the subject.

Considering this initial limitation, the results indicate that by the date of this systematic review, it was not possible to identify a standardized approach about what characterizes an innovative engineering course. We have some examples of global innovative universities, such as: Babson College, Stanford University, Massachusetts Institute of Technology, University of Michigan and Olin College of Engineering. This can be a difficulty in our work, since most approaches shows a certain specific subject.

In most of the selected articles we found reports that unite innovation to knowledge. Usually with the application of a flexible and interdisciplinary curriculum matrix, the engineering student will add a more extensive knowledge to the curriculum, becoming a proactive and complete professional that can represent a crucial success factor for the university that strives for innovation.

In addition, we presented several teaching methodologies to aid in the teaching learning process of an innovative engineering university. Considering the quality of the teaching learning process, we believe that PBL is an essential tool to achieve broader educational goals, not only the acquisition of knowledge by the students, but the development of skills and attitudes that will help them in their future professional life.

FINAL CONSIDERATIONS

This paper presented a systematic review of the literature to characterize innovative education courses in engineering under some perspective, realizing that an innovative teaching in an engineering college can be complex, due to its different factors, such as course curriculum, flexibility in the disciplines, interdisciplinarity, teaching methods, teachers and students. We analyzed 32 articles selected by the Web of Science database, and to classify these articles we created filters with some keywords and titles, with the contribution presented in Table 1.

We hope this systematic review can encourage managers to clearly define strategies to enhance and promote innovation and research within higher education in engineering schools, and also assist in the implementation of educational innovation system in Brazilian and overseas universities.

The research also aims to provide a theoretical framework to help future researchers in innovation in higher education. As a suggestion for future work, we propose a deep analysis of an innovation system in a Brazilian engineering university compared to other international models.

REFERENCES

Bailey, D., Bennett, J.V.1996. *The realistic model of higher education*. Quality Progress. Milwaukee, USA, 77-79.

Barrows, H. 2001. Problem-based learning (PBL). *University PBL*. Available at http://www.pbli.org/pbl (accessed date June, 16, 2014).

Christiansen, D. 1992. New Curricula. *IEEE Spectrum*. **29** (7).

Dertouzos, M. L., Lester, R. K., Solow, R. M. 1992. The MIT Commission on Industrial Productivity, “Made in America - Regaining the Productive Edge”. *MIT Press*, Massachusetts, USA.

Dochy, F. et al. 2003. Effects of problem-based learning: a meta-analysis. *Journal of Learning and Instruction*. Available at http://www.elsevier.com/locate/learninstruc (accessed date June 04, 2014).

Gijselaers, W.H. 1996. Connecting problem-based practices with educational theory. In:Wilkerson, L., Gijselaers, W.H., eds. *Bringing problem-based learning to higher education*. Jossey-Bass Publishers, San Francisco, USA, 13-21.

Grimoni, J. A. B. 2014. Capacitacao e Formacao Continuada para Docencia em Cursos Superiores de Tecnologia e de Engenharia. Chapter. IV. In: Oliveira, V. F. et al. *Desafios da educacao em engenharia, capacitacao docente, experiencias metodologicas e proposicoes.* ABENGE, Brasília.

Goldstein, H., Drucker, J. 2006. The economic development impacts of universities on regions: do size and distance matter? *Economic Development Quarterly.*, Sage Publications 20- 22.

Hadgraft, R., Prpic, J. 1999. The key dimensions of problem-based learning. In: 11th Annual Conference and Convention of the Australasian Association for Engineering Education. *Proceedings*. CD-ROM. Adelaide, Australia, 26-29.

Lopes, A. R. C., Moreira, A. F. B., Carvalho, M. A. de O. 1998 *Diretrizes Curriculares para o Ensino Superior*. Rio de Janeiro, published by SR-1/UFRJ.

Masetto, M. Innovation in higher education. 2003. *Interface - Comunicacao, Saude, Educacao*, **8** (14).

Mota, R. 2011. O papel da inovação na sociedade e na educação. In: Colombo, S.S. (Org). *Desafios da gestao universitaria contemporanea.* Artmed, Porto Alegre.

Samford University 2000. Center for problem-based learning research and communications. Available at http://www.samford.edu/pbl.html (accessed date April, 24 2014).

Savin-Baden, M. 2000. *Problem-based learning in higher education: untold stories*. Open University Press, Buckingham, UK.

Stepien, W., Gallagher, S. 1998. Problem-based learning: as authentic as it gets. In: Fogarty, R. *Problem-based learning: a collection of articles.* Arlington Heights, Skylight, USA, 43-49.

Stinson, J.E., Milter, R.G. 1996. Problem-based learning in business education: curriculum design and implementation issues. In: Wilkerson, L., Gijselaers, W.H., eds. *Bringing Problem-based learning to higher education*. Jossey- Bass, San Francisco, USA, 33-42.

Sousa, A. C. G. de. 1990. O Ensino na EE/UFRJ no Ano 2000. *Proceedings*. XXXXII Reuniao Anual da SBPC.

Sousa, A. C. G. de. 1997 A Formacao de Engenheiros para os Tempos Atuais. *Proceedings*. XII Simposio Nacional de Ensino de Fisica, Belo Horizonte.

Sousa, A. C. G. de. 1998. Diretrizes Curriculares para a Engenharia do Ano 2000. *Proceedings*. IV Encontro de Ensino de Engenharia, UFRJ/UFJF, Petropolis-RJ.

Sousa, A. C. G. de. 2000. Design Based Teaching of Software Engineering. *Proceedings*. ICECE 2000 – International Conference on Engineering and Computer Education. IEEE, Sao Paulo.

Vasilca, G. 1994. Engineers for a new age: how should we train them? *International Journal of Engineering Education*. Dublin, Ireland, **10** (5): 394-400.

Von Linsingen et al. 1999. Eds. *Formacao do engenheiro: desafios da atuacao docente, tendencias curriculares e questoes contemporaneas da educacao tecnologica*. Editora da UFSC, Florianopolis, 13-27.

Wilkerson, L.; Gijselaers, W.H.. 1996. *Bringing problem-based learning to higher education*. Jossey-Bass, San Francisco, USA.

Woods, D. 1996. Problem-based learning for large classes in chemical engineering. In: Wilkerson, L.; Gijselaers, W.H., eds. *Bringing problem-based learning to higher education*. Jossey-Bass, San Francisco, USA, 91-99.

Woods, D. 2000. Problem-Based Learning: how to get the most out of PBL. Available at http://www.biology.iupui.edu/Biology?HTML_Docs/biocourses/k345/PBL_Web_Page (accessed at November 06, 2014).

Zabala, A. 1998. *A pratica educativa: como ensinar*. Artmed, Porto Alegre.