Competencies developed by Production Engineering students: towards tree criteria for evaluating production system projects at the University of Brasilia

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Abstract

The University of Brasília has adopted the Project Based Learning (PBL) approach in the Production System Projects courses (PSP) in the Industrial Engineering Major. The evaluation of the competencies developed by students during the PSP is based on a methodology developed from a Decision Tree containing the essential skills desired for the deployment of an Industrial Engineer. The tree has two macro criteria that are the technical skills – subdivided into Project Management and Related Courses – and Transversal Competencies. This article aims to present and detail the evolution of this evaluation methodology based both on the development of measurable criteria of technical competencies and on the studies of Bloom and Krathwohl. The proposed methodology ensures to evaluate the technical knowledge of the students in a complete and detailed way, allowing not only to verify the performance of the learners, as well as to monitor their progress throughout the project courses.

Keywords: Production engineering; project approaches, engineering competencies.

1 Introduction

Recent researches have shown the concern of university staff regarding engineering education methods. The gaps in traditional teaching methods have caused changes in the engineering curriculum. Many of universities develop teaching practices with active learning, resulting in a greater student satisfaction and a more effective learning process. The majority of these practices are related to the development of projects. Active learning requires that students do more than simply watching, listening or taking notes in classroom. Some methods adopted can be described as asking the students to explain a complex concept, answering a question, building a flow chart, solving a short problem, answering a case study etc. These methods drive students to think and find a quick response to questions.

According to Guerra and Kolmos (2011) several active learning models based on projects are being developed through related experiences and researches everywhere. Problem Based Learning (PBL) curriculum in higher education shows greater learning satisfaction and motivation; self-confidence in student's professional abilities; better preparation for job market; and develops more competent professionals in comparison to those that have traditional learning.

The PBL approach has been successfully used in Aalborg University, Denmark, since 1974. In the first year, the main objective is to teach students how to work in group. In the following year, the project work is mainly course-oriented and exhibits characteristics such as interdisciplinary knowledge, innovation projects, lectures to support the project, visible and clear progression, construction of knowledge, collaboration for innovation, teacher as mediator, physical space to foster teamwork, group assessment, etc. At the end of the graduation course, the work is project-oriented, in which the students deal with unsolved problems within science and their profession, using a *know-why* approach. (Guerra and Kolmos, 2011).

Felder and Brent (2010) conducted a survey in which they identified the motivation of many participants of NETI (National Effective Teaching Institute) in adopting or increasing the use of teaching strategies that are known for improving the student's learning process. The NETI goals are to improve the participants´ teaching effectiveness, promote their engagement in scholarly teaching, and motivate them to participate in instructional development at their universities.

Among several teaching strategies, Oakley et al (2007) observed that well-known educational theories demonstrate that students learn more effectively through interactions with others. Cooperative learning leads to significant gains in academic success, quality of interactions with classmates and in college experience.

In the second part of this paper, we discuss the engineering competencies, specifically the production engineering competencies, explored through Project Based Learning (PjBL) approaches. Part 3 presents the methodology and the structure of the research. In part 4, we demonstrate the core basis of the research, which represents the restructuring of the sequential decision tree proposed by Santos et al (2012) in PAEE2012 Symposium. In addition to that, part 4 also covers the criterion used in the technical competence of project management for the courses of Project Production Systems (PSP) in the Production Engineering Graduate course at the University of Brasilia (UnB). Finally, part 5 brings the conclusion of this study.

2 Engineering Competencies in PBL e PjBL approaches

The increasingly competitive and fierce market is demanding recent graduated engineering professionals whose skills are only previously acquired in a considerable time after their graduation ends. This is due to the occurrence of constant changes in technology and problems to be dealt with (Da Silveira and Scavarda Carmo 1999; Vest 2006), the expansion of the social role of engineer, dealing with problems that transcend the technical sphere, assuming a political and administrative role (Da Silveira 2005; Vest 2006) as well as the requirements around the increased well-being of society, leading to the need of preparing innovative and entrepreneuring engineers.

In this scenario, Project Based Learning is an excellent way to develop important abilities in engineering students. According to Noordin et al (2011), PjBL enables learning the interaction needed to teamwork, strengthens abilities and acquisition of technical knowledge and the development of attitudes and behaviours to enable them to deal with coming professional environment. Forsythe (2005) said that this methodology enables students to acquire knowledge of specific and general content, such as human resources management and projects, problem solving, communication, collaborative work, team leadership and related areas.

Not only Project-Based Learning, but also the other active learning methods, like Problem Based Learning, Collaborative Learning and Cooperative Learning, have shown to be an effective means of increasing the development of attributes that would otherwise be difficult to develop in a traditional engineering curriculum (Shuman, 2005).

2.1 Competencies of Production Engineer

Industrial engineering is area that is growing fast in comparison to other engineering courses, recently. The main demand of this area comes from industrial companies that need to provide products and services that combine high reliability, innovation, competitive pricing, manufacturing processes and distribution of sustainable and low environmental impact (Slack; Chambers; Johnston, 2002).

Compared to other engineering areas, it is evident that production engineering has stronger a management focus. Fae and Ribeiro (2005) mentioned that the change of Industrial Engineering into a more managerial component is probably due to the fact that courses in the area of Science Business Administration are not focused on main problem solving, conducting their training in a more analytical feature. This difference enables the professional of industrial engineering to deal with problems related to the mobilization of technical resources within the profession to perform tasks in the company he/she works.

According to the Brazilian Association of Production Engineering, ABEPRO (2001), the competencies of the Industrial Engineer can be conceptualize as: know how to deal with complex situations, analyse it to know what to do, use their knowledge, through their skills and work with their particular attitudes.

These skills are necessary to the successful education of a production engineer, many of them obtained only with more practical experience. This is the case of the Production Engineering undergraduate at the University of Brasilia (UnB) that adopted in its curriculum a set of seven courses of Project Production Systems (PSP) applying the PjBL methodology. Each of these seven courses is linked with a theoretical course such as Engineering Economics, Planning and Production Control and Information Systems. These courses have tutors for each project and a specialist teacher in the desired technical knowledge (related course) in project methodology and other transversal knowledge. In addition to acquiring knowledge of the applied technical content, the methodology also allows the acquisition of transversal knowledge that can be applied by using the principles, methods and techniques for skills such as teamwork, project management and sustainability, and that are aimed to be incorporated into as proposal of problem solutions.

3 Methodology and structure

In this research, we have applied the Multiple Criteria Decision Analysis (MCDA), also known as Multiple Criteria Decision Making (MCDM). It is a sub-discipline of Operations Research that provides tools and procedures to support decision-making when it involves more than one variable. We will now present the methodological process used to develop this research, the Analytic Hierarchy process (AHP). It was developed by Thomas L Saaty in the 70's, and it is a MCDA and has a wide variety of applications, including group decision-making on subjective problems. The process can be summarized as the following steps:

1 – Decide the goals of the research

2 – Decide which criteria and sub-criteria to use

3 – Build the sequential decision tree

4 – Determine the relative weights between the criterion through the pairwise comparisons

5 – Determine the relative weights between the subcriterion of the same criterion trough the pairwise comparisons

5 – Check if the comparison is consistent, and if not, adjust them

6 – Decide which options you want to evaluate

7 – Compare those options on each subcriterion

8 – Apply the weights of the criterions and subcriterion

9 – Judge the results

4 Development of sequential decision tree

The sequential decision tree is a structural input of the AHP method (Analytical Hierarchy Process). It aims to structure the important criteria for the assessment of student performance throughout the courses of production systems projects. The Sequential decision tree, helps the student assessment objectively, and also enables the quantification of the evolution of students along the development of the projects.

The work proposed by Santos, et al. (2012) presents the beginning of this tree by structuring criteria based on key requirements for the preparation of a production engineer with emphasis on Project Management. The proposed tree was branched into two macro criteria: "Project Management Skills", referring to the skills needed to perform such a function, and the "Technical Skills" which are the academic skills necessary to the preparation of the production engineer. However, only the macro-criterion "Skills in Project Management" was subdivided. Therefore, the purpose of this study is to develop the criterion "Technical Skills" and present developments made in restructuring the tree.

4.1 Restructuring the sequential decision tree

The sequential decision tree based on the AHP method (Analytical Hierarchy Process) structures the important criteria for the assessment of student's performance throughout the courses of production systems projects. The decision tree, helps student's assessment, enables the quantification of the evolution of the students on the seven projects developed. The changes made include the relocation of criteria in the tree structure, and the development of the criteria "Technical Skills", pending in the previous work proposed by Santos et.al (2012).

The new decision tree proposes splitting the macro skills assessed and worked in the PSP courses into "Technical Skills" and "Transversal Skills." Figure 1 illustrates the new structure of the decision tree, including new technical skills to be described in section 4.2.1.

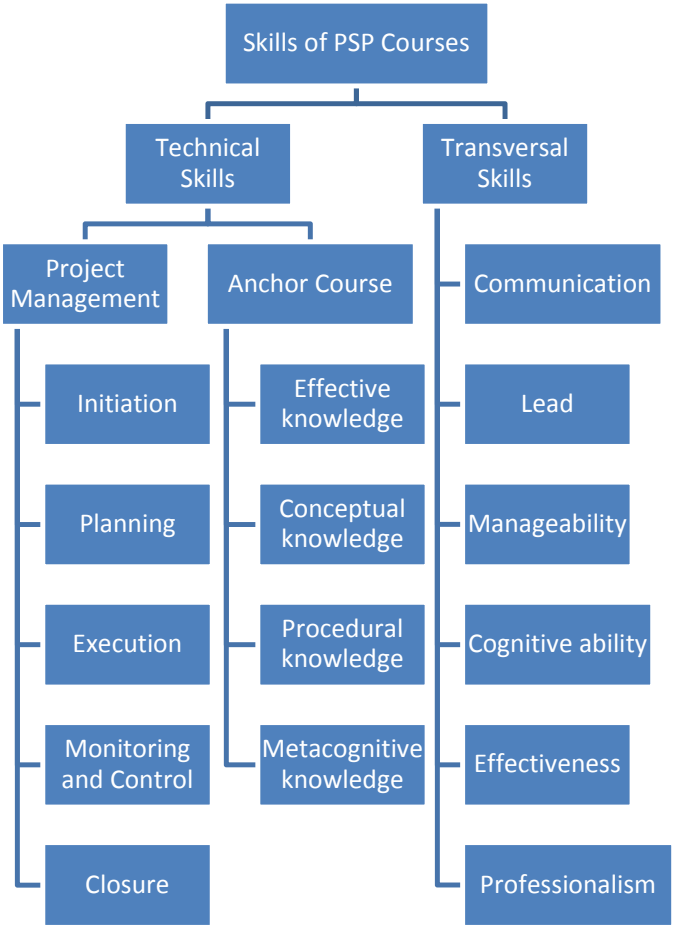

Figure 1 - Remodelled sequential Decision Tree

4.1.1 Technical Skills

The "Technical Skills" criterion is now subdivided into two sub-criteria: Project Management Skills, located in the previous work as a macro criterion, and "Skills Related with the Anchor Course", to be detailed in this work for the first time.

4.1.1.1 Skills Related to Project Management

The courses of Production Systems Project are characterized by the development of the design solution for a problem situation and their main sources of quality assessment are the deliveries made during the course. Within this criterion, it is necessary to assess how students are applying knowledge, skills, tools and techniques in activities to meet project requirements (PMBOK, 2000).

In the previous structure of the decision tree, the criterion related to Project Management used to be evaluated by the project management plans along the three course deliverables: preliminary project, intermediary project and final project. The new proposal is based on the five process groups (Initiating, Planning, Executing, Controlling and Closing) described in "A Guide to the Project Management Body of Knowledge" – 4th Edition [Project Management Institute (PMI ®) December 2008] for assessing the skills of project management. Based on these criteria, it is possible to evaluate the students' ability of defining the problem, balancing options, choosing a path, implementing and evaluating the solution throughout the project cycle.

The completion of the criteria tree structure occurred by the definition of the components of Technical Knowledge in which students would be evaluated in the courses of Project Production System.

Based on the process table presented by Krathwohl (2002), which was generated through a review of the proposed structure on Bloom's Taxonomy, it defined the main criteria of Technical Knowledge, under which other sub-criteria were defined in order to provide a more detailed perspective, as shown in the figure 2.

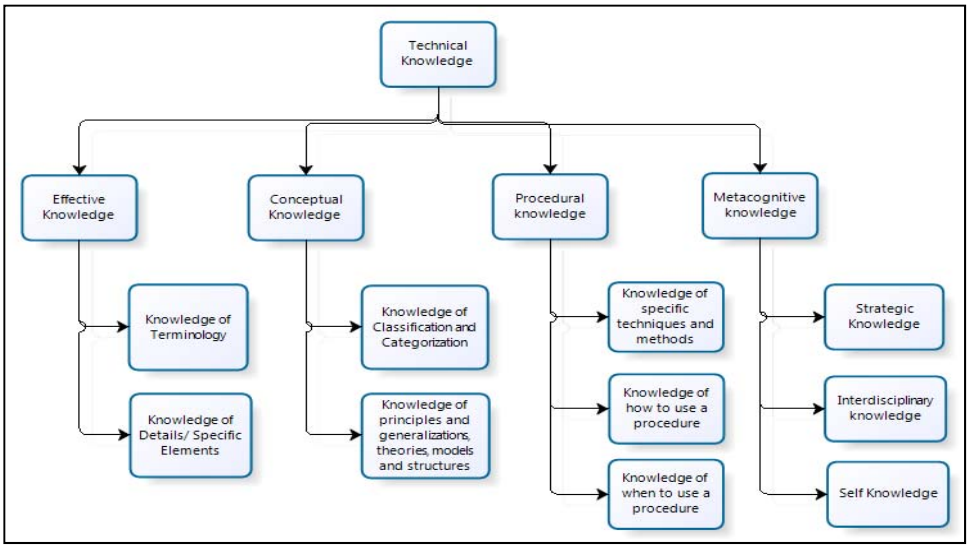

Figure 2 – Technical Knowledge for evaluation of PSPs

The four main technical knowledge presented criteria of the tree that are equivalent to the "Knowledge Dimension" column of the Bidimensional Table of Bloom's Taxonomy. Based on the taxonomy proposed by Bloom (1956), adjustments were made in accordance to the field of study concerned by defining the sub-criteria of Technical Knowledge.

The Effective Knowledge of Technical Knowledge Tree criteria has as sub-criteria the Knowledge of Terminology and Knowledge of Details/Specific Elements. Knowledge of Terminology describes the basic characteristics of knowing the meaning of descriptive or operational terms commonly used in the related course of the project that students are performing. On the other hand, Knowledge of Details/Specific Elements is a more detailed knowledge about the concepts of related courses. Ideally, the groups of students should cite several concepts of the related course and choose some others to deepen (those who are directly used in the project). In this deepening they are responsible for listing the characteristics and properties of these concepts, sources of information about them, events that led to their use, all those who were involved in its use, etc.

Conceptual Knowledge has as sub criteria Knowledge of Classification and Categorization and Knowledge of principles and generalizations, theories, models and structures. The first criterion consists not only of the ability of students to know the types of classification of a given subject, but also to know how to identify which types are best suited for use in the project. It is necessary to determine whether the study was actually done in each category/class of some subject to come to conclusion of what would be the most appropriate type to be used, and not just randomly done. It also consists of identifying the importance order of each subject for the project development.

In the second one, teams of students must use principles, theories and methodologies from the related courses to justify and explain the answers or solutions found. They also must make a clear and cohesive connection between theory and practical part worked on the project, ensuring that the methods used were not only understandable to the expert, but also to all those who read the written work and watched the presentation.

The third criterion, Procedural Knowledge, consists in knowing how to do a specific task: Skill, algorithms, techniques, tools and methods. It was split into three self-explanatory sub-criteria: Knowledge of criteria for determining when to use appropriate procedures, Knowledge of course-specific skills and algorithms and Knowledge of course-specific techniques and methods.

Metacognitive Knowledge, the last criterion, was added by Krathwohl (2002) and represents the knowledge about one's cognition and its awareness. This criterion was split into three sub-criteria: Strategic Knowledge, Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge and Self-Knowledge.

4.1.2 Transversal skills

The criterion of Transversal Skills, previously classified as a sub-criterion within Project Management Skills, now becomes a macro isolated criterion which will be assessed according to the personal characteristics of the student. These features were divided in Communication, Leadership, Management, Cognitive Abilities, Effectiveness and Professionalism based on the Project Manager Competency Development (PMCD) Framework 2 º PMI edition (2001).

4.2 Criteria for management of projects

Each criterion is subdivided in sub-criteria related to specific abilities or competencies. The criterion “initiation” is related to student ability to understand a problem situation presented by the tutor at the beginning of each PSP course. Besides that, other sub-criteria are the ability to identify the parameters needed to characterize the proposed problem and the ability to propose a feasible solution for that problem.

The “planning” criterion, in turn, can be divided in five sub-criteria: Selection of solution methods; Identification of activities needed to solution development; organizing these activities in work process; anticipating future events and ability to use project management tools.

The “execution” and “monitoring and control” criteria are related to the development of the planned activities, so it makes it possible to evaluate the following skills: Technical knowledge on project management methodologies; teamwork coordination; Ability to adapt work processes to unforeseen situations and field of measurement techniques, evaluation and registration of the proposed activities.

Finally, the "closure" criterion seeks to assess: Capacity selection and ranking of information to be presented; Domain standards of writing and presentation of work and capacity for learning and self-assessment from adjustments to the project planning initially proposed.

The evaluation of proposed criteria for Project Management is taken from three deliveries throughout the course, according the PMBOK Guide. The initiation criterion is evaluated from the delivery of the Project Chart (PMI, 2008) carried out in the fourth week of the PSP project. The Project Chart is assessed by the tutor team and then returned to students, so they can begin to plan the project development.

During the following two weeks the students can work on the project planning definition. At the sixth project week the students have to deliver the Project Plan (PMI, 2008). Then, having the Project Plan as a benchmark, and the tutor as a specialized Consultant, students can start the execution phase. During the following seven weeks both execution criterion and monitoring and control criterion are continuously monitored.

Finally, at the end of the course the students deliver the last assessment tool, called Project Report, needed to finish the project management criteria evaluation. The tree of criteria for project management seems to be promising but still is under development,

5 Conclusion

This research has showed the technical knowledge that can be used to identify engineering students profile, when taking Production Systems Project courses. This tool will be used along the courses as a mirror that will reflect students expected abilities in dealing with projects issues, as well as a reference guide to evaluation of student’s performance. Effective, conceptual, procedural and metacognitive knowledge are categories identified that gathers the students competences in regards to projects skills, that is, the technical knowledge that can be used as a reference for evaluation students. In regards to transversal competences that can be developed, we have come to a set o categories aligned with the project management lifecycle such as initiation, planning, execution and closing. Thus, we have a basis for analysing student’s production taking as a reference the tools and deliverables that students used or produced.

This case study has also showed that the use of PBL as a means to teaching project management is like hand in glove. Also, the use of engineers desired profile from the industry and the project management best practices are an effective parameter towards which we may drive engineering education. The use of Multiple Criteria Decision Analysis (MCDA) in the definition of the method and also to design a decision tree has helped us define the specific technical knowledge to evaluate students’ skills.

We hope that the proposed method of defining these criteria can be useful not only for professors working with the same challenges of identifying and evaluating their students, but mostly to help reinforce engineering curriculum in seeking for more effective teaching methods and reaching successful educational results, mostly with the use of PBL and PjBL as their main tool.

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