SYSTEMS-APPROACH DESIGN OF AN UNDERGRADUATE STEM PROGRAMS ACADEMIC METHODOLOGY

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ABSTRACT

The goal of education is to empower students with knowledge and skills required to enter their professional lives and bring added value to society, through successfully tackling complex socio-technical problems. Yet, many programs have been designed without duly considering how that end goal is to be achieved. In addition to the students, other stakeholders need to be factored in.

This paper describes how effective undergraduate programs in the science, technology, engineering and mathematics domains were designed following the systems approach. The identification of the learning objectives led, through consideration of all stakeholders and their requirements, to the identification and evaluation of alternative academic methodologies. The selected one was project-based-learning coupled with continuous assessment. Although project-based learning is well known, alone it does not render the required results. Feedback is a pivotal element in any educational process and continuous assessment proved to be the true learning enabler when applied in project-based learning environments. Projects are executed in an incremental manner, going from course-specific projects, through trans-disciplinary projects that span across several courses, to the final capstone or graduation project. Connection with industry is always close and is articulated in multiple cooperation strategies; the main ones and the lessons learned are summarized. Being validation essential in the systems approach, this paper shows how validation was recurrently performed and how the collected feedback was used to fine-tune and improve the methodology.

The main results achieved in over six years are presented. Moreover, the road ahead is presented with the sketch of a third element that will further reinforce the effectiveness of the methodology. Students' self-assessments bring gradually implemented, to complement the methodology. It helps students develop the maturity required to have proper awareness of the quality of the work they perform, so as not to have to rely entirely on external evaluations.

KEYWORDS

Systems, approach, academic, methodology, standards: 7, 8, 11, 12.

THE SYSTEMS APPROACH

An approach is a way of going about tackling a problem. Systems have been designed and developed by human beings for centuries. In 1637 the French mathematician and philosopher René Descartes published his famous Discourse on the Method of Rightly Conducting the

Reason and Seeking Truth in the Sciences (Quintás-Alonso, 1999). One of the four precepts that Descartes formulated gave name to that specific way of conceptualizing systems, namely the reductionist approach. Specifically, that precept, which was one of the main tenets in the Discourse, was the idea of dividing and conquering. Problems that could not be solved due to their size and complexity were decomposed into parts, and each part further again into smaller parts if so needed, down to a level at which the parts could be solved. The integration of the solutions would then be the solution to the original problem. The approach was clever except for the fact that it neglected the interaction among the parts, which normally are as important as the parts themselves. The growing complexity of the systems that were required around the middle of the 20th century, as well as the awareness of the importance of the relationships among their parts or components, fostered a new paradigm in the conceptualization of systems. The need to deal with multi-faceted problems, to integrate multiple disciplines and to exercise a global view meant the advent of the discipline of systems engineering, also known as the systems approach (Blanchard & Blyler, 2016; Blanchard & Fabrycky, 1981; Sage, 1992). Figure 1 depicts the eight elements of the systems approach (Sols, 2014). The last decades have witnessed an unprecedented growth in the adoption of the systems approach across all industrial domains, as well as in academia, which is reflected by the exponential growth of programs on systems engineering worldwide, that has gone from one in the 50´s to over three hundred nowadays (INCOSE & SERC, 2017).

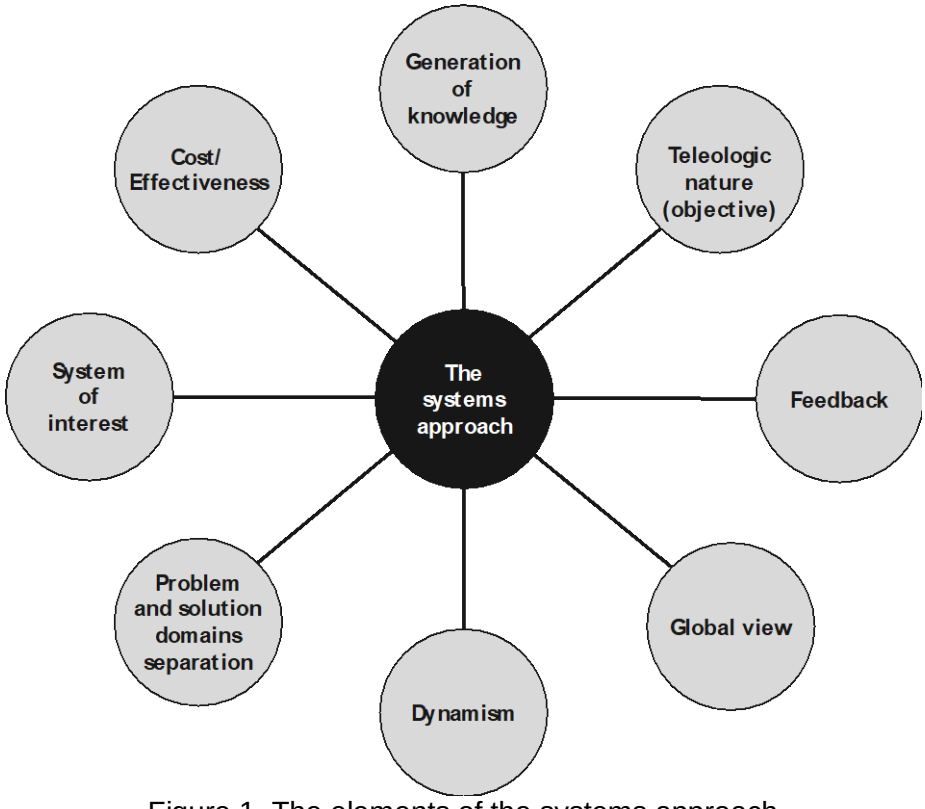

Figure 1. The elements of the systems approach

LITERATURE REVIEW

Pivotal to the success of any academic program is that the institution running it is a learning organization, capable of capitalizing on lessons learned and of sharing the knowledge, always

developed at individual's level. The systems approach was described as the fifth discipline, the one that characterizes learning organizations (Senge, 1990). After Senge's seminal book, other authors have expanded into how to build truly learning organizations (Edmondson, 2012; Garvin, 1993; Garvin, Edmondson, & Gino, 2008). Efforts to develop the academic methodology should build on recommendations and lessons learned. A significant number of sources proved valuable, particularly on the Conceive, Design, Implement & Operate (CDIO) initiative (Bankel et al., 2005; Berggren et al., 2003; Ceawley, Malmqvist, Lucas, & Brodeur, 2011). Furthermore, the fostering of continuous improvement and the value of assessment were considered (Davis & Aydeniz, 2007). After project-based learning was selected, several sources were checked for continuous development and improvement of the methodology (Boss, 2015; Ho & Brooke, 2017).

THE DESIGN OF AN ACADEMIC METHODOLOGY

In 2011 a decision was taken to improve the academic methodology, adopting the best practices in order to ensure effective achievement of the education goals. The drivers were the vision, mission and values of Universidad Europea, compiled in Table 1.

Table 1. Vision, mission and values of UEM

Vision	At Universidad Europea, we consider academic excellence to be one of our strategic pillars. Thus, our educational model has embraced the principles of the European Higher Education Area based on the individual's holistic learning. In this model, the professor is a mentor as well as an adviser who supports the student throughout their university life. The student, on the other hand, maps out their own educational journey, developing the knowledge, competencies, skills and values demanded by society at the moment.
Mission	To provide our students with comprehensive education, educating leaders and professionals who are prepared to respond to the needs of a global world, to contribute value in their professions and to social progress through an entrepreneurial spirit and social commitment. To generate and transfer knowledge through applied research, likewise contributing to progress and positioning ourselves at the cutting-edge of technical and intellectual development.
Values	**Collaborative**: We bear the seal of approval that sets up apart for our entrepreneurial spirit: we are resolute and audacious, placing the student at the forefront. We collaborate and work together to implement the best practices at our institution. **International**: As members of the Laureate Network we have a global vocation and scope while retaining strong local roots. We offer international resources to support and strengthen local education. The magnitude and influence of the Laureate Network enable us to provide our professionals and students with excellent opportunities. We are an inclusive, multicultural organization that values diversity and respects all cultural perspectives and characteristics. **Analytical**: We implement a rigorous self-assessment process to constantly increase our information and knowledge so as to improve our

	performance. This reflexive approach, based on data analysis, sets us apart from other institutions. **Trustworthy**: If we want to be "here for good" we must gain the trust of our students and their families, employers and the communities where we operate. All levels of our organization are subject to the highest demands; we work with integrity and assume full responsibility for our actions. **Audacious**: We are entrepreneurs; we strive to be audacious and are willing to take calculated risks while at the same time basing our decisions on rational, reflexive planning. We are quick to leverage opportunities and make positive changes in order to enrich our students' experience. We search for new ways to improve learning without borders and transform the traditional educational model. We have an innovative mentality and we provide members of the university community with the chance to challenge the status quo. We apply creative approaches to education and business. We never cease to explore new approaches, new technologies, new business models and new theories. We are leaders, not followers. **Responsible**: Assuming responsibility for our students' results is the cornerstone of our revolution in the field of education. We focus on students and employers to adapt our programs to their needs. We strive to maintain high rates of retention, graduation and employability so that our students joining the labour market generate a positive social impact.

The systems approach was applied, to begin with, by considering the ultimate goal of academic programs, as generically defined in the Vision and Mission, and as specifically described in the competencies to be achieved in each program, which are detailed in their corresponding Degree Reports. In addition to focusing on the goal and to identifying the customers (the students), all other stakeholders were acknowledged, together with explicit identification of how they could influence the quality of the programs, or be affected by them. Among the stakeholders, it is worth mentioning the following: companies and institutions, which are the desired employers of the students who graduate; ANECA and Fundación Madri+d, respectively the national and the regional agencies for quality accreditation and assessment; other Spanish universities offering the same academic programs; and entities providing institutional and programmatic quality seals. Feedback was understood as validation of the goodness of the selected approach, to be continuously carried out due to the dynamic nature of the academic environment. Several methodologies were considered (design concepts, in systems engineering terminology), and the selected one was project-based learning (PBL). PBL has been successfully applied and has been consistently advocated for by top institutions (Alan Leshner and Layne Scherer (Editors), 2018; Graham, 2018). Many authors have also documented the power and benefits of PBL (Larmer, Mergendoller, & Boss, 2015; Wurdinger, 2016).

The systemigram depicted in Figure 2 portrays the multiple cause-and-effect relationships that gravitate around the quality of academic programs. The result was the selection of PBL, to be coupled with two other key elements: continuous assessment (feedback being always instrumental in the systems approach) and student's self-evaluation, fostered in order to help students develop and mature as professionals. The three elements that integrate the methodology, that could be thought of as *enhanced project-based learning*, together with the Vision, Mission and Values, integrate the so-to-speak academic DNA, depicted in Figure 3.

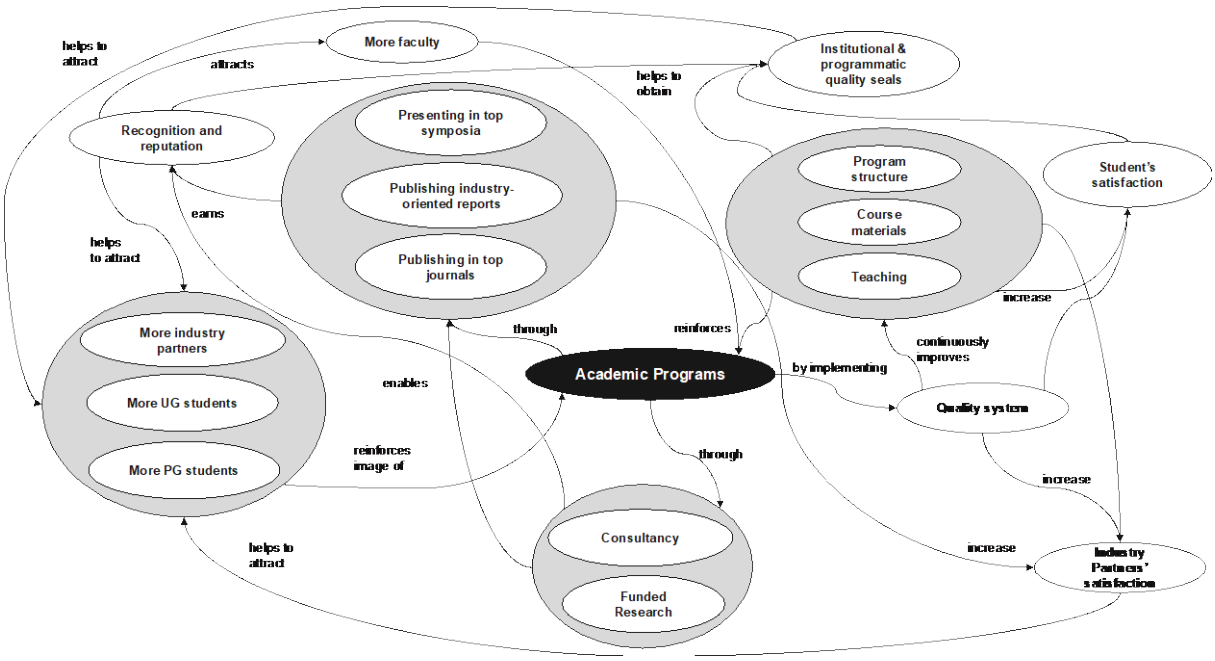

Figure 2. Systemigram that portrays cause-and-effect relationships

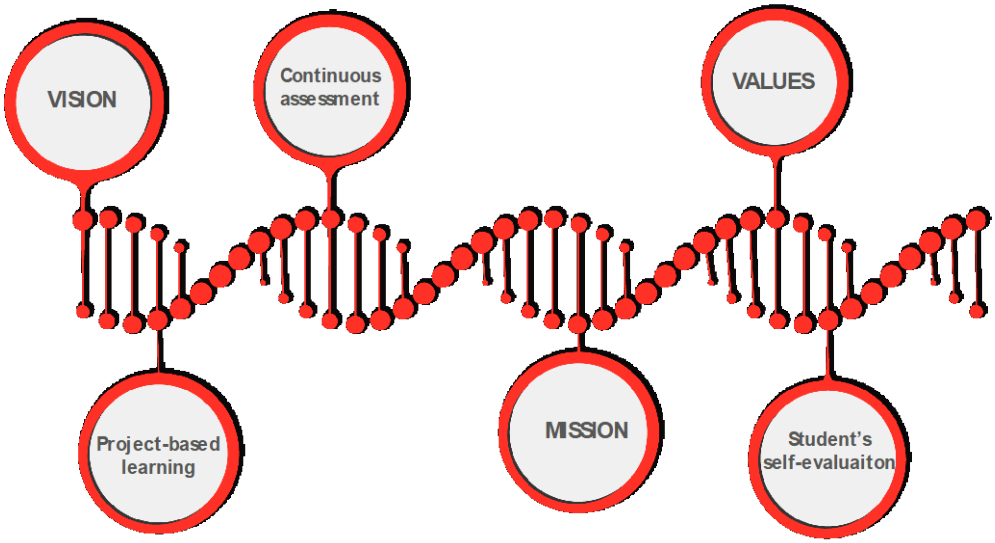

Figure 3. Drivers and elements of the academic methodology

The difference between enhanced PBL and conventional academic approaches is substantial, as can be seen in Figure 4. In enhanced PBL marking is still discrete, although much more diluted throughout the semester, and feedback is given continuously; that feedback is what really leverages learning, which is the ultimate goal of any academic program.

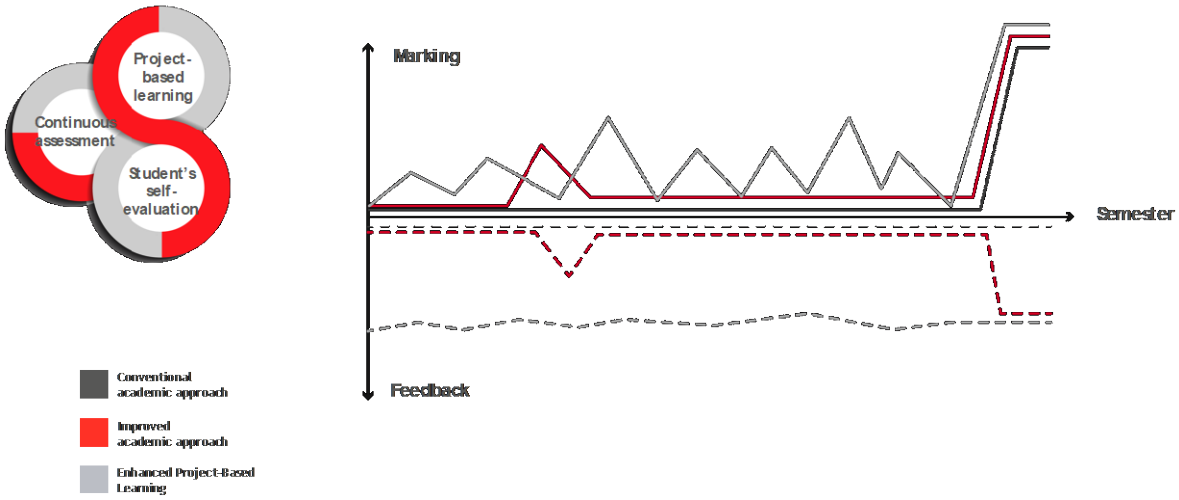

Figure 4. Enhanced project-based learning

Pivotal in the academic methodology is the so-called integration projects. All academic programs have learning objectives, and the necessary studies are divided into subjects, and correlations are made between them. Usually, there are 40 subjects in a single bachelor's degree and between 10 and 20 in a graduate degree. The underlying hypothesis, as important as it is often forgotten, is that students combine all of the knowledge they acquire in their different subjects. In the real world, there are no purely accounting, thermodynamics, algebra, strength of materials, marketing, or humanities problems, to name a few common subjects in different programs. Graduates are supposed to be well-educated professionals able to apply what they've learned and help solve complex problems. However, those problems have multiple facets: social, technical, economic, legal, ethical, etc. As a result, professionals must be able to employ all the necessary resources from what they've learned and created the appropriate synergies. Unfortunately, the majority of academic systems make teaching into a knowledge silo; students learn each subject but are not able to develop an overall view involving all of the things they've learned. Students pass and graduate, but don't fulfil the true objective of learning. The Graduation Project is insufficient to bring together and put into practice everything students learn. This is frequently brought to light when many graduates join the workforce and show their inability to apply that holistic vision to complex social and technical problems. In the project-based learning method, students work on several projects in different courses each academic year; this allows them to support the theoretical knowledge they've gained with practical activities. One can only consider to have understood, what one can apply successfully. But the method goes much further than that. In the integration projects, students work on a project in which they must simultaneously apply the bodies of knowledge from several subjects. For example, in the Industrial Systems Engineering Bachelor's Degree an extraordinary project involving two subjects is carried out: Theory of Machines and Mechanisms and Automatic Systems and Control. In Aerospace Engineering there is an

impressive project involving no less than four subjects: Fluid Mechanics II, Aerodynamics and Aeroelasticity, Graphic and Mechanical Design, and Management Skills.

A big picture vision is precisely one of the key elements of the systemic approach, the paradigm for analysis and complex problem solving. An academic method simply cannot be envisaged if it does not stimulate and support the big picture vision, where students really combine everything they have learned and are able to successfully put that knowledge to use. The experience shows that through those integration projects, the walls of the knowledge silos are torn down and students are able to really see the big picture. The effect is even more extraordinary when several integration projects are done over the course of their studies. The important thing is not only to understand what should be done, how, and why; one must create the appropriate automatic systems to avoid the frequent gaps between theoretical knowledge and knowledge applied in practice. The human brain works in two modes: automatic, or system 1, and conscious, or system 2. With integration projects, students get used to combining areas of knowledge, which affords them that extraordinary automatic system to take on problems with a global or holistic view. This is what makes them into true professionals able to add value to their companies, their customers, and society in general.

All approaches need to be validated, and so has been the adopted methodology. The last six academic years have witnessed a substantial improvement in the performance of our students, as captured by key performance indicators such as Net Promoter Score, Attrition Rate, and Graduation Rate. Moreover, companies have shown great interest in, and support of, the projects conducted in class. Every year a Project-Based School Awards ceremony is held in September, at which the best projects from the previous academic year (selected by the faculty) are presented to the companies that attend. It is the representatives from the companies who vote and select the winners. Last September over 30 top-level Spanish firms, to include a number of multi-national companies, attended the Award ceremony and picked the winners. Very frequently it is the companies that suggest the topics, at the beginning of the academic year, on which the students can work. This close cooperation between industry and academia is pivotal to the success of the academic model and to the overall student's experience. A number of papers have been published on the implementation of the methodology (Terrón López, García García, Velasco Quintana, Gaya López, & Escribano Otero, 2015; Terron-Lopez, Archilla, & Velasco-Quintana, 2017; M.J. Terrón-López et al., 2016; M. J. Terrón-López, Velasco-Quintana, García-García, & Ocampo, 2017).

If the integration projects enable the integration of areas of knowledge within the degree pursued, extra-curricular activities conducted in clubs and associations allow students from different programs to work together. This environment comes extremely closet o what they will find in their professional lives when they will need to work together with professionals from other backgrounds. For example, it is normal to see in the activities carried out in the Formula Student Club or in the Robotics Club, to name a couple, students from degrees such as industrial engineering, software engineering, design, and even students from degrees offered by the other colleges, such as marketing students or economics students from the School of Social Sciences and Communication. Learning to work with students from other programs, undertaking the same challenges and generating synergies from their varied backgrounds, is what forges true professionals capable of adding value to their employers and to society, at large.

The combination of project-based learning (especially, through the performance of integration projects) and of extra-curricular activities in clubs and associations is what accelerates the learning curve and the development of the needed professional skills. The experience

gathered over many years, with a large number of alumni have demonstrated their competences in a large array of firms, validates the goodness of this academic approach. This capability of educating real professionals is, precisely, the ultimate goal of academic education.

CLOSURE

Project-based learning, coupled with continuous assessment, has proven to be a wonderful academic methodology. Being the goal of any program for its students to attain a certain level of understanding and command of the corresponding body of knowledge, the putting into practice of the conceptual foundations presented in class is what truly enables students to master the knowledge and to be capable of successfully putting it into practice, to contribute to the solving of problems. When on top of that the self-evaluation is fostered in students, their maturity spikes. Project-based learning demands that students question everything, not taking anything for granted. This helps them to learn how to learn, which is the ability we all need throughout our professional lives.

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BIOGRAPHICAL INFORMATION

Dr. Alberto Sols is the Dean of the School of Architecture, Engineering and Design. He has over 35 years of combined experience in industry and academia and has published over 30 papers and five books. He is focused on academic methodology development and his research is mainly in systems engineering and performance-based logistics.

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