An Innovation Model in Curriculum Design for Teaching Engineering at Universidad EAFIT

Claudia M. Zea
Universidad EAFIT
Medellín, Colombia
Email: czea@eafit.edu.co

Alberto Rodriguez
Universidad EAFIT
Medellín, Colombia
Email: arodrig@eafit.edu.co

Natalia A. Bueno
Universidad EAFIT
Medellín, Colombia
Email: nbuenopi@eafit.edu.co

Abstract*—Constant changes in technology pose continuous challenges for higher education institutions that are training the engineers of the future. These changes are making it necessary to adapt the curriculum in order to develop the skills needed by the XXI century engineer. Moreover, instead of thinking in a large curriculum reform at a specific moment, it is necessary to define curriculum management processes that include change as a natural component of the process. In addition to these global trends, each institution has a particular context and thus, the analysis in each institution has unique characteristics, a common methodological approach, and a reference model that can be built as long as it is flexible enough to include that context. This paper describes a model developed for curriculum management inside the School of Engineering at Universidad EAFIT - Colombia. This model includes the institutional context and is based on a process approach defined by the Business Process Management (BPM) methodology. The model uses the Burlton Hexagon as a theoretical framework to identify organizational structure, strategies, policies, infrastructure, technology tools and human capital. It is also a mechanism for specifying curricular macro processes including the global and institutional context. The proposed model is based on three pillars: (a) scientific research in education, which promotes the use of the scientific method as a strategy to ensure an approach to problems based on evidence which allows the construction of educational innovation projects, (b) education engineering focused on engineering education, which transforms the learning by developing basic, professional, and transversal skills as well as those specific for an engineer of the XXI century, and (c) interactive educational communities, both face to face and virtual, as spaces for knowledge management that support collaborative working and experience-sharing, managed by its members working together promoting initiatives to develop educational innovation projects focused on specific topics, that answer questions related to teaching and learning needs. The formulation and development of educational innovation projects are the responses to different needs identified on specific courses that are transformed into research questions. These projects aim to renew the curriculum so that it dynamically evolves based on classroom experiences. Thus, the curriculum renewal is based on critical thinking about the problems found in engineering education. The use of the scientific method and the collaborative approach enables drawing solid conclusions based on the experimental results. The model proposes the formulation and development of innovative educational projects in which scientific research applied in education aims to transform teaching, academic and administrative practices. As consequence, curricular innovations that integrate learning objects and educational, methodological and assessment strategies, are developed by an interactive learning community composed by teachers. Finally, the results obtained by applying the model in some courses in the School of Engineering of Universidad EAFIT are presented. These results include reducing the drop-out rate of students, redefining admission and graduation profiles, and micro-curricular redesign based on competences using projects, among others.

Keywords*—Engineering education, scientific research in education, interactive educational communities, educational innovation projects, curriculum development, process management

I. Introduction

Engineering education aims to prepare engineers to succeed in a changing work environment, thus students must be motivated to acquire new knowledge and develop new skills on their own. Its objective is to provide, besides the technical knowledge and the skills to apply it, the flexibility to adapt to different situations and the capacity to understand the context. Therefore education in Engineering, in addition of taking into account social, economic and political aspects of the practice of engineering, must promote that students develop skills in teamwork, communication, etc., according to their talents, knowledge and skills as well as their own ways of thinking, creating and doing.

Engineering education trains students to become modern and efficient engineers, that are able to participate and lead processes of conception, design, implementation and operation of projects related to systems, products and production systems. To do this, students must be prepared not only technically, but they also have to be socially responsible and have the capabilities to innovate permanently. The required areas of knowledge are not limited to science, arts, technics or technology. Today, it is required to understand the evolution and history of the society they belong to, and therefore, it is important that students can acquire knowledge about economics, sociology, psychology, and semiotics, among others.

II. Context

The School of Engineering at Universidad EAFIT has defined its institutional guidelines for engineering education around five areas: (a) learning through projects, (b) modeling and simulation, (c) integration of technology as a tool for the design and construction of artifacts, (d) the characterization of matter, and (e) management of the details in manufacturing and objects realization [2]. This model defines the engineer at Universidad EAFIT and it is a fundamental component of the profiles defined for both students and alumni of the programs offered by the School of Engineering.

Based on this principles, the curricular proposals for each undergraduate program offered by the School of Engineering

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at Universidad EAFIT were built in various stages between 2006 and 2007. The process, led by the Dean of the School, was developed in different phases that started by rethinking the curriculum of each program, then identifying common elements between them, and finally, formulating new curricular axes used to develop the full proposal.

The curriculum was rethought based on the institutional guidelines for engineering education defined by the School of Engineering. This lead to the conceptual design of a new Engineering Building conceived as part of the celebration of the 30th anniversary of the foundation of the School and opened in 2010. The building is based on the concepts of innovation and technology so all students of the School, in this learning environment, can materialize the ideas they have created throughout their careers, and is oriented to let them be the masters of their own learning.

For that reason, the building is conceived to be a space for thought, creation and execution, more for learning than for teaching, generating proud and a sense of belonging. A place where students, by means of this learning environment, can translate the ideas that engineering has encourage since its origins, back in France (genie) and England (engine): creation and machine, think and build, mind and hand, science, know-how, art and technique, and all ideas that have prevailed through the history of the profession and have oriented the learning of engineering.

On the other side, among the guiding principles of the formation stated by the Institutional Educational Project of Universidad EAFIT[1], it is recognized that education should be focused on the person. This implies, from a curricular perspective, to offer more flexible curricula to allow students to choose how to complement their professional training, offering the possibility to choose between humanistic, cultural and/or artistic training, all according to their skills and personal preferences. From the pedagogical perspective, it is learning, not teaching, the center of the educational process, implying a shift in the focus of the process from professors to students.

Additionally, the University Development Plan 2012 - 2018[2] defines three goals: (a) to preserve academic excellence, (b) to become a teaching university with research, and (c) to improve national and international projection. This implies that academic programs should do more than transferring concepts and must promote the creation of new knowledge through research processes, accompanied by a permanent review of the curricula to verity that they meet the objectives.

The organizational structure of the School of Engineering at Universidad EAFIT is based on academic departments and academic programs. The School currently has seven academic departments, each offering an undergraduate program: Geology, Civil Engineering, Product Design Engineering, Mechanical Engineering, Process Engineering, Production Engineering and Systems Engineering. The School is led by a Dean and each academic department has its own director. Each academic department designs the curriculum for the undergraduate program, but it must be aligned with: the mission of the institution, the guiding principles, the Institutional Educational Project and the current development plan.

There are different bodies at Universidad EAFIT that are related to curricula management: the academic council, the school council, and a career committee for each academic program. According to the statutes of the University, the Academic Council's functions include the approval of "the curricula of the academic programs" [3]. The School Board is responsible for the approval of "course syllabus and to assure they are followed each semester" [4] and of promoting "studies on the relevance and on the updating of the syllabus of the different courses offered by the School" [5]. Finally, the Career Committees have "competition as an advisory body on academic and curricular matters" [6]. The Dean of the School as "manager and developer of the comprehensive development of the school in the academic, cultural fields, and management" [7] is responsible for formulating the policies and guidelines that govern the curriculum development of the School. The dean is a member of both the Academic Council and the president of the School Board.

Additionally, an Excelence Center for Teaching and Learning was created in 2010 and it was named Proyecto 50 since it was established to celebrate the 50th anniverary of the University[8]. Proyecto 50 seeks three objectives: (a) to enhance the skills of faculty to innovate in the processes of teaching, learning and creative research; (b) to promote curriculum management processes; and last but not least, (c) to provide the University with physical and virtual spaces where teachers have access to the cutting edge technology and can receive advice and support to transform their classroom practices.

The academic program's directors should be permanently reviewing the relevance of the curriculum offered, in a joint effort with the career committee and the faculty of the program. Proposals for micro-curricular renewal are presented to the Career Committee as advisory body and then to the School Board for approval. Deeper changes in the curriculum structure of each program must follow the same steps, but are presented to the Academic Council for final approval.

It is a fact that many modern engineering projects require a combination of several disciplines. Thus, engineering schools should not try to develop these contextual skills and processes through separate courses but make them part of all existing courses, use activities outside the classroom where the multidisciplinary and collaborative active learning is developed, and take into account the different learning styles of students.

Such education is essential for achieving productivity, entrepreneurship and excellence in an environment that is increasingly based on technologically complex systems that must be sustainable. For all the above, we conclude that a better job must be done for preparing future engineers, and we must do it through a systematic reform of engineering education.

Given this context, it is important to have clearly defined academic processes so the University can respond flexibly to these new challenges that appear continuously. By having processes for curricula design that allows not only collaborative work among peers, but also a permanent update of the faculty, the University can obtain and maintain a high quality curriculum that enables it to achieve academic excellence.

Although the School of Engineering at Universidad EAFIT has been making curricular revisions to adjust their programs to new requirements, it is important to incorporate into these

academic processes the latest theories and tools to ensure a curriculum that allows the training of new professionals that will face the challenges of tomorrow. The next section describes an innovation model for curriculum design that allows the education of these new engineers.

III. Proposed model

In this section, the theoretical framework used to formulate the innovation model is presented briefly. A detailed description of the model, and specifically of the methodology used, can be found in [17]. The development of the model was based on process management and BPM[1] methodology. Particularlly, the Burlton Hexagon was used to model the institutional context and the macro-processes for curriculum design (see Figure 1).

The proposed model enables the design of curricula for engineering education according to the philosophy of the School of Engineering at Universidad EAFIT. Specifically, the model follows directives proposed by the School such as constantly looking to strengthen the research capabilities and provide a pedagogical, academic and administrative management aimed to achieve academic excellence, among others. This proposal is based on a conception of engineering education that is: (a) focused on the training of engineers aimed at developing knowledge and skills that allow them to face the challenges of the future and of a globalized world; and (b) supported by the process of engineering education in engineering and scientific research in education.

The model is based on three pillars: (a) scientific research in education, (b) engineering education in engineering and (3) educational interactive communities. Scientific research in education promotes the use of the scientific method as a strategy to ensure an evidence-based approach to problems. Thus, research and innovation projects are based on needs and difficulties in specific areas or subjects in the curriculum. Just as any research project, a research question is the starting point and processes for conceptualization, implementation, and analysis of results are conducted using the Participatory Action Research approach.

Engineering education in engineering, means to apply the principles of engineering to education focused on the education of the engineers, this transforms the learning processes so students develop basic, professional, transversal skills needed by the XXI century engineer.

Communities of practice, and specifically educational interactive communities, are spaces for knowledge management, both face-to-face and virtual, that enable collaborative work and sharing of experiences. The objective of incorporating them in the model is to be able to manage the collaborative work and promote the development of educational innovation projects focused on specific topics in order to provide answers to specific teaching and learning needs.

The model, being based on educational innovation projects, scientific research in education, teaching practices, academic practices and administrative practices, becomes an innovative curricular proposal that integrates learning objects and educational, methodological and assessment strategies, developed by the members of a community of practice - faculty, academic program directors and heads of departments- that allows the socializing of experiences, knowledge management and collaborative work.

The model was built as part of a research project whose main objective was to define a process for creating and designing curricula for engineering programs at Universidad EAFIT. A process based on scientific research in education and education engineering applied to engineering education in order to assure that engineers graduated from EAFIT develop all skills needed by the XXI century engineer. To achieve this goal, the following specific objectives were defined: (a) to identify, based on the Institutional Educational Plan and other official documents of the University, the strategies, policies, human capital, infrastructure, technology and organizational structure of the institution; (b) to identify curricula referents to support curricula construction for engineering programs at Universidad EAFIT; (c) to establish stages for definition, design, construction and review of the curriculum by working either individually or collectively, both in virtual and face-to-face spaces; (d) to define mechanisms to manage the processes of resources and expertise creation and sharing, in order to enable the creation of new knowledge and link it as part of the curricular information and content; (e) to define iterations throughout the life cycle of curricular construction and design, in a way that continuous improvement and continuous monitoring of each processes can be granted; (f) to incorporate processes of socialization and interaction by articulating the virtual and face-to-face spaces that allow collaborative work; and (g) to specify workflows, dependencies and roles, supported by the principles of scientific research in education and collaborative work through communities of practice, for the processes that must be carried out for the curricular construction in the different engineering programs offered by Universidad EAFIT.

The Burlton's Hexagon is used to describe the proposed model since it is a representation that allows the articulation of all the strategic aspects of the organization or, as is the case, of the School of Engineering at Universidad EAFIT, and the identification and integration of the key aspects of the processes if performs; more specifically, processes related to curriculum management. The proposed model is the result of developing each component of the Burlton's Hexagon in the particular context of curriculum management in the School of Engineering at Universidad EAFIT.

The following is a brief description of the axes:

1) **Strategy.** It defines the final objective of the organization and it is the base to track performance. Additionally, it includes the different perspectives of the organization, the stakeholders and the processes, as well as purpose and strategic aspects such as: vision, mission, objectives and strategies. This axis is defined based on: Institutional Educational Project, the University's Rector Principles and Institutional Guidelines defined by the School of Engineering for training engineers.

[1]BPM, Business Process Management, is a discipline for modeling, automating, managing and optimizing business processes [9]. To achieve this, it is necessary to develop processes with the aim of aligning, in a controlled way, the strategic aspects of the business. This articulation is represented by means of the hexagon propose by Burlton in 2008[10]

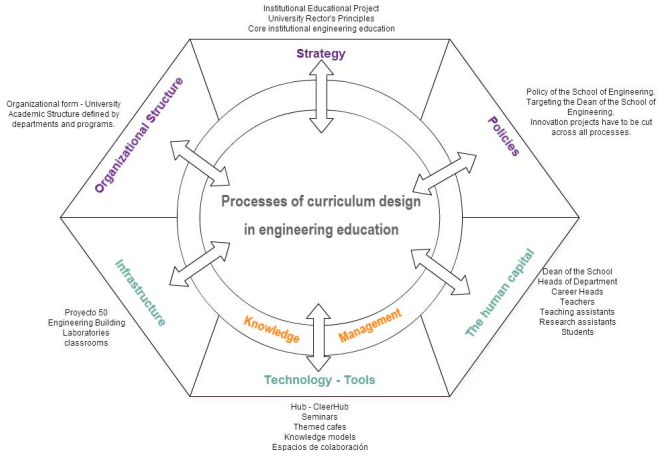

Fig. 1. Burlton's Hexagon for the model

In addition, it defines, as the main strategy, the processes of scientific research in education that allow the construction of projects for innovation in engineering education.

2) **Policies.** It defines the policy framework which includes: legislation, business policies, decision criteria, rules, governability requirements, and business principles, among others. This axis is defined based on: the policies of the School of Engineering at Universidad EAFIT, the directions provided by the Dean, and innovation projects as components transversal to all the processes related to curriculum design.
3) **Human capital.** It includes human resources and human capital in the organization that enable the achievement of the goals and objectives. It reflects: skills, knowledge, competences, capabilities, and motivation, among others. The team that will carry out the processes of curriculum design is composed by:
   a) *Dean of the School.* He is responsible for convening the members of the practice community to participate in various spaces of socialization and for supporting various innovation projects that are being developed.
   b) *Heads of Departments.* They are responsible not only of participating in socialization spaces but also to be active in innovation projects that are carried out in the Academic Department.
   c) *Directors of Academic Programs.* They are responsible of participating in socialization spaces as well as of being active in innovation projects that are carried out in academic departments that offer courses to the program.
   d) *Teachers.* They are responsible of participation in socialization spaces as well as of being active in innovation projects that are carried out in the academic department to which they belong and the specific area of the curriculum in which they participate.
   e) *Teaching assistants.* They are responsible of actively participating in innovation projects related to the curriculum areas they support.
   f) *Research assistants.* They support the processes of scientific research in education inside pre-established innovation projects (usually they are master students that enrich the research work with their own research).
   g) Students. Students have two roles: (a) participate in innovation projects and (b) provide feedback on the results of the innovation projects that have been implemented in the classroom.
4) **Technologycal Tools.** It is the axis that defines all technological tools that support the processes in the organization: Applications, devices, connectivity, databases, and infrastructure, among others. Platforms such as hubs [1] allow the creation of dynamic Web sites that support scientific research and educational activities. For the particular case of this model, CleerHub [2] was used aimed to expand and maintain the research capacity in engineering education. Members can post content, materials, and tools in order to generate reflections about the research-oriented education in engineering in which they are working. The spaces of socialization and collaborative work such as thematic cafes, seminars, meetings, construction of research proposals, knowledge models, among others are also part of this axis.
5) **Infrastructure.** It includes all installed capacity available to support business processes: work spaces, facilities, infrastructure, and virtual spaces, among others. The infrastructure is both physical as well as technological. The physical infrastructure needed to complete the processes set out in this model consist of: (a)meeting rooms, where training activities based on collaborative work can be offered; (b) spaces available in Proyecto 50 and the Engineering Building, which were created to reflect the concepts of innovation and technology; (c) classrooms and laboratories, where the proposals and classroom practices constructed by the actors of this model are carried out. The technological infrastructure is conformed by that that provides access to the virtual community and allows activities such as video conferencing, virtual meetings, among others to take place.
6) **Organizational structure.** It includes all aspects of the organizational structure such as: organizational chart, roles, functions, and responsibilities, among others. It also reflects organizational goals, organizational objectives, and performance incentives. As mentioned before, the model is aimed at organizational structures as that held by Universidad EAFIT: A university organized in Schools, departments, administrative areas, academic programs, and research groups, among other components.

Once the six axes are identified, the processes for curricular design are structured. They must be coherent with the elements identified in the axes of Burlton's Hexagon. The set of macro-processes is based on the pillars of the proposal: scientific research in education, engineering education focused on education of Engineering and interactive educational community[18]. The following is a brief description of the macro-

processes and curricular processes proposed in the model.

The macro processes are (See [17] for a detailed description):

1) To identify a need or difficulty in a specific area of the curriculum. Teachers, program directors and heads of academic departments work collaboratively to review and identify a need or difficulty in a curricular area. This macro-process is supported by: the Dean, heads of the departments, program directors and faculty members of the School. This macro-process is completed through the socialization of ideas and experiences in the interactive educational community.
2) To formulate the central research question. Faculty, program directors and heads of departments work collaboratively on the developing of a guiding question, in accordance with the proposal of scientific research in education. It is important to identify the complexity of the need or problem to be addressed and the amount of knowledge that can be generated. The research question guides the construction and development of the innovation project. This macro-process is supported by: the Dean, heads of department, program directors, faculty members of the School and Proyecto 50. This macro-process is completed through the socialization of ideas and experiences in the interactive educational community.
3) To develop the project using the approximation of scientific research in education. Teachers, heads of departments and program directors collaboratively develop the project with the strict rigor of the scientific method and construct a hypothesis, that will be the base for the construction of the proposed new practices in the classroom. As the research advances, teachers, heads of departments and program directors, socialize partial and final achievements with the interactive educational community. Each of these processes is supported by: the Dean, heads of department, program directors, faculty members of the School, Proyecto 50 and disciplinary experts. This macro-process is completed through the socialization of ideas and experiences in the interactive educational community.
4) To define new classroom interactions that transform educational practices. Teachers, heads of departments and program directors collaboratively define objectives, methods and activities to be carried out inside the classroom. This is done by applying an engineering approach to engineering education and, with the support of Proyecto 50, build new educational content and participate in teacher-training to allow the adoption of new practices and interactions. All this construction is already supported and socialized within the interactive educational community.
5) To enriching learning environments for students. Faculty, heads of department and program directors collaboratively create new learning environments for students within the classroom. Observation, analysis and permanent storage of results must be part of the process. All this construction is already supported and socialized within the interactive educational community.
6) To assess the experience. Teachers, heads of department and program directors assess all investigative and teaching activities carried out. The result of the evaluation is socialized with the interactive educational community.

IV. Application of the model

For the application of the model, an interactive learning community was formed. The members of the community are teachers, academic programs' directors, heads of departments, and the Dean. In this community, the sharing of experiences has generated a culture of permanent review, reflexive evaluations and critics of practices and performances in their own work. They also have promoted initiatives that enable open academic discussions that promote the innovation mentality that leads to the design and development of educational research projects focused on achieving academic excellence. These projects benefit students, faculty and the academic community in general. The philosophy of scientific research in these projects is used with the purpose of inquiring, researching and generating new knowledge about educational processes. All spaces, virtual and face-to-face, aim to socialize experiences and provide permanent support to research and innovation processes. One of the proposed spaces is the Thematic Cafes, which use a methodology of knowledge management through the developing of socialization strategies. They start with specific themes about innovation projects. Moreover, the sequence of topics to be covered in each of these thematic cafes is selected so they add value to the research processes that teachers are developing and promotes the generation of new proposals.

Based on the aforementioned, a roadmap for the development of this proposal was established. Initially, teams composed of faculty from each of the seven Academic Departments affiliated to the School of Engineering were formed. These working groups, with the participation of the head of the department, the program director and the dean, were collectively responsible for designing research projects and educational innovation based on a research question and the needs and difficulties in specific areas and subjects. Additionally, different spaces for reflection and socialization, led by the Dean of the School, were created such as: workshops, thematic cafes, meetings, groups in CleerHub, just to mention a few.

The development of innovation projects was defined as a systematic process in which participating teachers start from a central research question that requires processes of conceptualization, implementation and analysis of results of the developed experiences.

Some of the innovation projects made by the faculty of the School are: (a) identification of learning difficulties in the course of Static Physics; (b) transformation of the subject of Automatic Control from competence development; (c) development of integration projects across the curriculum in Production Engineering and Systems Engineering; and (d) identifying how the subject of Graphic Expression can achieve better skills for engineers in their creative process, among others.

These educational innovation projects have encouraged teachers to be linked in research and collaborative structured interactions where they have the opportunity to review new information, reflect on their own practice, and analyze the results they are getting in the classroom. Additionally, the projects motivate them to: (a) develop basic skills in teaching strategies, planning, assessment and evaluation; (b) seek new ways of educational experimentation to look for more positive results in their work; and (c) encourage the creation of new materials or adapting existing materials to the current needs of their area of expertise.

This model have produced results such as: (a) reducing the dropout rate from 30% to 10% in courses which are part of the basic training of engineers in the areas of Mechanical Engineering, Civil Engineering, Production Engineering and Product Design. This was achieved with the construction of an automatic assessment and feedback system that allows students to perform activities such as: review of content, practical exercises and presentation of online exercises and workshops; (b) micro curricular redesign of integration projects (capstone courses) in different areas, where the core competencies to be developed in the student were updated; (c) the competence-based redesign of courses with analysis of the initial and final profiles of students taking them and building knowledge models for describing in detail each of the skills developed; (d) online tools for supporting the core courses that the school offers to its students, i.e. a pre-calculus course to provide the student with the concepts requiered for the freshman calculus courses; and (e) an academic writing course to provide the students with tools for writing essays and other kinds of written tasks.

V. Conclusions

- The application of the model at EAFIT University, has allowed the developing of innovative educational projects whose results have been positive and have transformed the quality of education inside the university's School of Engineering.
- When experiences are socialized, the interactive educational communities created under this proposal can generate reviews, critical evaluations and reflective practices and performances in their work, as well as prompt initiatives that enable openness to innovation, design and development of projects focused on improving the learning process of students, faculty and the academic community. This, in turn, allows joint research processes that generate knowledge and promote research activities in education, and generates a shared educational culture regarding values, principles, concepts and practices in curriculum, instruction, assessment, organization and functioning of the institution.
- A strategy for change in the curriculum should be an institutional initiative that relies heavily on the academic and administrative practice in such a way that it takes into account both the organizational structure as well as the culture of the institution.
- The School of Engineering at University EAFIT, aware that it must have a curriculum based on educational research and an interdisciplinary management, through this new approach has succeeded not only in impacting the training process, but also in profiling its students and graduates in line with the global challenges an engineer must face in the XXI century.
- The research projects integrate curriculum, educational, methodological and assessment strategies, not only for transforming classroom practices and academic programs, but also the processes of curriculum management, teaching, research, and management of an institution. Thus, the competencies required by the engineer of the future are developed, while teacher development and educational management are strengthened, and expands the research capacity of the community of the School of Engineering.

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