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Research paper

Competences of graduation for the curricular redesign of mechanical engineering based on local and national development agendas

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Abstract

This article proposes the implementation of CDIO (Conceive, Design, Implement and Operate) in the curricular redesign of the career of Mechanical Engineering. It presents a binding scheme of shared learning between the industry and academia to obtain graduate competencies, as a basis for curricular redesign. A new educational model is designed which allows the transition from know what to know how; interlacing the disciplines that intervene with skills and abilities to solve projects focused on local and national realities. It was defined that of the CDIO, standards 2, 3, 5 and 7 apply. This generates a student-centered curriculum with complementary disciplines, interlaced with inter and intra-personal skills, product manufacturing, processes and systems. This proposal considers specific knowledge, skills, values and attitudes that must be applied in the integral formation of Mechanical Engineers, in order to respond to the socio-productive needs of the country. Finally, the curricular redesign determines the areas of professional academic impact in Design, Energy, Materials and Production Management, taking into account the graduate competences and in a complementary way the learning results of the subjects of the career.

Keywords: *Curricular Design; Learning Achievements; CDIO.*

1. Introduction

The development of new curricular design proposals must consider socio-productive realities according to the time, which must pose challenges that are limited to three priority nouns: globalization, competitiveness and quality. The knowledge economy, as a new context, implies a geopolitical distribution based on the greater and better productivity in which education has a primary role.

Speaking with a proactive vision, it is essential to locate our country with an emerging economy in this new geopolitical vision that moves towards a geo-academic mapping. For this purpose, the reference of the QS World University Rankings 2017-2018 [1], has been taken. In the first places stand Massachusetts ' Institute of Technology (MIT), Stanford University and Harvard University. In Latin America, the best centers of higher education are the Pontifical Catholic University of Chile (Chile), the State University of Campinas (Brazil) and the University of São Paulo (Brazil) [2]. The Ecuadorian universities appear in position 57 of the QS (# 400). Ranking of Universities in Latin America shows # 69 the Escuela Superior Politecnica del Litoral (ESPOL), # 71 the Pontificia Universidad Catolica del Ecuador (PUCE), # 114 the University of the Armed Forces (ESPE), # 147 the University of Cuenca. From # 151 to # 200 there is the National Polytechnic University, the Central University of Ecuador, the Santiago de Guayaquil Catholic University, the University of the Americas, Ecuador [2], evidencing that Ecuadorian universities are not part of the top 50 in higher education in Latin America.

At present there are studies confirming that careers or higher education cooperative programs (training and talent development between universities and businesses) aid to close the gap between theory and practice in engineering education [3]. With respect to the professional development of university students, they indicate that participation in cooperative educational programs will provide the student advantages, such as: the development of their talent, negotiation skills and work experience, as described by the model called "the reflected professional". It is based on a competitive person who obtains professional experience in a systematic way and uses it to further improve the knowledge acquired in the classrooms [3].

Current and future professionals who are trained in the Ecuadorian education system are part of a globalized world. Therefore, they are exposed to multiple beliefs, multidisciplinary, transnational and decentralized knowledge networks which demand a high content of responsibility in decision making, based on elements of judgment to look for changes in flexible and limited production systems, for which interrelated work and academic competences must be considered.

Crawley et al. (2007) described an approach to education in engineering as a complement to a comprehensive set of inter, intra and personal skills linked to academic subject knowledge in engineering, in order to develop innovative engineers and entrepreneurs [4]. It is thought that Conceiving, Designing, Implementing and Operating (CDIO) is a simplified model to improve engineering education, where integrated learning experiences lead to the acquisition of disciplinary, personal, inter and intra-personal knowledge as well as product and process development [5].

Every academic project has as options, to continue with the conceptual and philosophical procedure of the traditional and classic model, propitious for a calm and slow reflection, or to opt for an analysis of contemporary society in which scientific and technological innovation rapidly transforms the knowledge society. While doing this, it needs to be kept in mind that Ecuador is also entering the Latin American trend of evaluating universities and academic projects as an indicator of efficiency.

In the case of engineering education in Ecuador, it has been difficult to adapt pedagogical educational models. This, due to de fact that a technical education model establishes as a principle “to know and to know-how”, which in fact is a substantive difference. The education in engineering in its beginnings did not measured the background of the global economic system and ignored the knowledge of the administration, the systemic thought, the capacity of teamwork , the professional ethic, the creative work in combination with the engineering design , etc. On account of this, it is important to plan and propose the construction of a new curricular design based on graduate, labor, professional, cognitive and training competencies for the Ecuadorian society, improving the quality of its graduates by using the principles of CDIO, considered as a new applicable methodology for engineering education. It is one of its aims to develop the ability to apply knowledge and to solve professional problems efficiently [6-35-36].

The curricular design should not be limited to teaching processes exclusively and assume that the student has learned. We should establish mechanisms that allow an effective process of learning to learn and learn to unlearn, based on good communication and self-training as a strategy in the Teaching - Learning Process (PEA). The vision of the CDIO model is to relate a systemic and integral approach to the design, implementation and evaluation of modern engineering education programs focused on students. This approach needs to provide knowledge, skills and abilities to solve problems from design to operation, with a deep mastery of the technical, scientific and technological base. Other important abilities inserted in this approach are to be able to lead teams that manage new products and processes, through the application of research in the development of technology, machinery, systems and production processes, product design and others, with social impact [7].

The development of competency-based curricula, rather than an intellectual fashion in the field of higher education, is a trend that is imposed in the world today, due to the demands of the work environment [8]. The curricular approach to the Mechanical Engineer career at The Technical University of Ambato (UTA) defines competition as "the knowledge, skills, attitudes, values that contribute to the integral formation of professional knowledge for socio - technological development as a means to built a relational model in our society ", transforming available human resources into competences. The proposal of this curricular academic project takes five inputs from a prospective analysis of society and the intention to evaluate the students´ performance based on their progress in acceptable minimum competences [9]:

1) The competences defined as a basic unit must link the formative ideals of the academic education with the needs of the labor sector. This research synthetized them as follows:
   - Basic competences: those of general education in engineering students generating a solid knowledge of physics, chemistry, mathematics, through theories, concepts and experimental practices.
   - Specific competences: developed in the fields of energy, design, materials, production management applied in mechanical engineering to solve real problems according to CDIO methodology, allowing an effective internal and external mobility.
   - Generic Competences: associate the formative ideals and the needs of the working world as a framework for applying a flexible and dynamic curriculum including: ability to solve problems, foreign language proficiency, citizenship competences, self-training capacity, and communicative action among others.
   - Labor Competences: knowledge, abilities, skills, attitudes and values that develop a real capacity to perform a job effectively, ensuring its final achievement.
2) CDIO is a new open environment proposal for applied education in engineering education created in the Massachusetts Institute of Technology. This focuses on productivity, innovation and entrepreneurship, through engineering and business projects. It establishes changes in the methodology of the PEA, through active learning and verifiable results specified prior to the application of the curriculum. The core principles are: Conceive: technology, customer needs, conceptual and technical business plans; Design: plans, diagrams and algorithms applied to projects; Implement: transformation of design into product; process that includes manufacturing, testing and validation; Operate: handle product or implemented process that delivers contribution to the value chain including maintenance and evolution [6] [10 - 12] [29 - 30].
3) National Plan of Good Living. - In Ecuador, it has been determined, as a state policy, the implementation of the change in the productive matrix. Around this policy some types of revolutions have been identified, such as: the economic, the productive and the agrarian revolutions. This has been done in order to overcome the inherited exclusion model and gear State resources to improve education, health, roads, housing, scientific and technological research, work and productive reactivation. All these in harmony and complementarity between rural and urban areas , determining strategies for change such as: I Democratization of the means of production; III Increase in real productivity and diversification of exports, V transformation of higher education and transfer in science, technology and innovation [13 - 14] [27 - 28] [32-33].
4) Management Model of the Government of Tungurahua - the UTA is located in the province of Tungurahua. It has a territorial area of 3,386.26 k m 2, with a population density of 289.4 in habitants per km2, considering only the arable and habitable area. The projected population is 518,114 inhabitants of which 59.1% are in the rural area and 40.9% in the urban area. In addition, it is a province, in relation to the economically active population, (EAP) eminently agricultural with 26.92% , manufacturing with 18.51%, commercial 16.59%, services 13.64%, transport 4.66%, construction 5, 03% among others [15-34].
5) Follow-up to graduates. - It is a statistical tool that collects information on the situation of graduates in Mechanical Engineering, from which a database for decision-making and career improvement curriculum plans is built.

The purpose of this article is to determine the graduation profile of the Mechanical Engineering career, conceptualizing the learning outcomes through the application of strategies that integrate the socio-industrial reality with the academy, applying CDIO methodology.

2. Methodology

The curricular design is a long-term academic project that must measure its impact in a cyclical way. Therefore, planning must identify a well - defined structure such that the final results and parameters of social impact are part of an efficient system of educational quality. The new curriculum must contain different skills that meet the needs of businesses and companies. These needs can be summarized in: good skills in technology management and management of human and financial resources. The approach must be based on decentralized learning and teaching, with the students being the subject of knowledge [16]. The project must start with a technical - regulatory mapping of the main features existing in each country. In the case of Ecuador, the Organic Law on Higher Education (LOES), the Regulation Academic Regime (RRA), the academic itinerary and the curricular organization [17]

[18] [31] are considered the framework for this proposal. Then, this methodology presents a related study to a relational model, breaking the paradigm of academic context with professional or employment context, by analyzing competences that are conceptualized in the curriculum redesign. The main axis is the definition of: areas of professional academic impact, exit competences and in a complementary way the learning results of the subjects of the career.
Secondly, a process must be defined to determine learning scenarios in which knowledge is identified, skills and attitudes needed to ensure strong graduate competences in an academic-industrial environment at local, national and international levels [19]. It is necessary to establish a guide for decision making, through the elaboration of dual matrices, which relate the challenges of mechanical engineering in the area of impact where the students develop professionally. Within this context, the analysis of the Objectives of the National Plan for Good Living 2013 - 2017 [13], the Prioritized Sectors (Change of productive matrix) [20], the Provincial Government Agenda of Tungurahua [15] a study of employability and the follow-up to graduates of Mechanical Engineering – UTA are the key factors considered, determining the areas of action in which a Mechanical Engineer can develop, as indicated in Illustration 1:

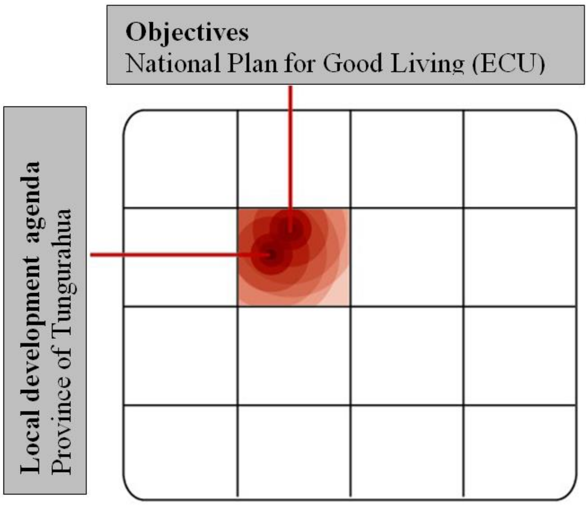

Fig. 1: Dual Matrix to Determine the Areas of Action in Engineering.

The analyzed matrixes are a cross between rows and columns, where professional action areas (professional skills) of mechanical engineering are defined. It seeks the solution of real problems applied to local and national development agendas that contribute to the traceability of curriculum design goals in the country [21]. These are considered the basis of "know-what" structure to define graduate competences, basic competences and specific competences [22].
The next step in the methodology synthesizes the reports of employability and follow-up to graduates, identifying the soft skills and labor competencies that should be developed in the new engineering professionals. As a complement, our students´ specific competences derived from their own experience in the field are considered. Thereby, the graduate skills with "know what" are proposed from the academic perspective and the socio - technological development of the country.
The last step of this proposal is the application of globalization and academic innovation for Mechanical Engineering. This promotes the internationalization of curricular design, which includes Conceive, Design, Implement, Operate (CDIO), by adapting the competencies found with the learning outcomes set out in the model, having to complement the proposal with learning strategies used by the students.

3. Results and discussion

After the applied methodology, the curricular organization is carried out, which is part of a linear and by levels educational model, based on LOES and RRA [23]. This model determines the knowledge, skills, attitudes and values, through sequential learning achievements towards the fulfillment of the proposed graduation competences, as shown in Illustration 2:

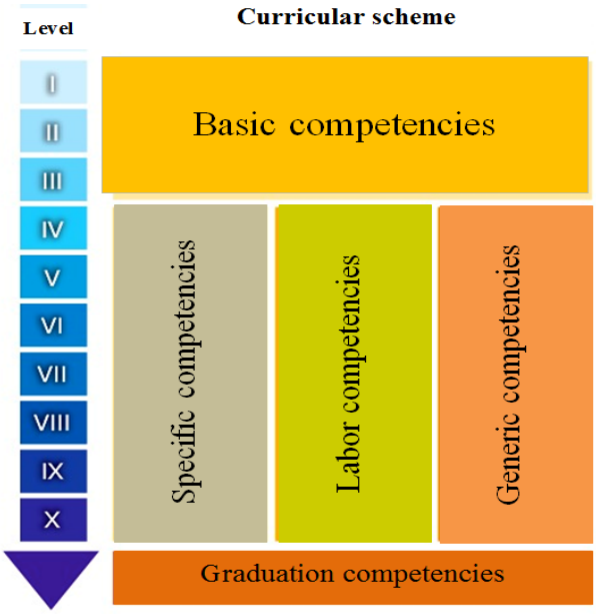

Fig. 2: Curriculum Organization in Mechanical Engineering.

The areas of professional action are established through the analysis of the matrix, in which the fields of action of the mechanical engineer are determined. The crossing between the National Development Agendas: PNBV and Development Agenda of prioritized sectors are considered, as indicated in Table 1.
The areas of action for the Mechanical Engineer determined by the matrix of Priority Sectors and National Plan of Good Living of Ecuador that these professionals demand are shown; determining that their impact is on: fresh and processed foods (92%), renewable energies (67%), metalworking, vehicles, bodyworks and auto parts (42%), among others.
From the analyzed areas of action that involve research and linkage with society between the Prioritized Sectors and the Provincial Government Agenda of Tungurahua that require professionals in mechanical engineering was also determined in the following areas: fresh food and processed (50%); leather footwear and leather clothing (67%); metalworking (67%); vehicles, motor vehicles, bodies and parts (50%) and construction (83%) as indicated in Table 2:
In addition, the action requirements of the undergraduate professional were used, structuring a process between the graduates' employability report, the thematic units and the learning achievements evidencing fulfillment of the competence in their environment, as indicated in Illustration 3:

Table 1: Comparison between the Prioritized Sectors (2015) and Objectives, Policies and Guidelines of the Good Living Plan (2013 - 2017)

Comparison: Strategic sectors vs. National Plan for Good Living (ECU)		Objectives: National Plan for Good Living												
		Objectives 2 - 2,11 - g	Objectives 4 - 4,4 -(h,k)	Objectives 4 - 4,6 -(a,c,f)	Objectives 7 - 7,6 -(c al f)	Objectives 7 - 7,7 -(a al d)	Objectives 7 - 7,8 -(a, b, e, h, k, m)	Objectives 7 - 7,10 -j	Objectives 10 - 10,2 -(a,b)	Objectives 10 - 10,4 -(c,i)	Objectives 10 - 10,5-d	Objectives 11 - 11,1- (s,t)	Objectives 11 - 11,5- h	**Percentage**
Strategic sectors	Sectors 1	X	X	X	X	X	X	X	X	X	X		X	95%
	Sectors 2		X	X			X		X		X			42%
	Sectors 3	X	X	X	X	X	X	X				X		67%
	Sectors 4		X	X			X				X		X	42%
	Sectors 5		X	X		X								25%
	Sectors 6		X	X		X	X				X			42%
	Sectors 7	X	X	X	X	X	X	X	X		X		X	83%
	Percentage	43%	100%	100%	43%	71%	86%	43%	43%	14%	71%	14%	43%	

Table 2: Comparison between the Prioritized Sectors (2015) and the Provincial Government Agenda of Tungurahua (2015-2017)

Similarity: Strategic sectors & Provincial agenda (Tungurahua)		Provincial agenda (Tungurahua)							
		Foods	Leather and footwear	Metal-mechanics	Environment	Furnishings	Plastic	Textile	**Percentage**
Strategic sectors (ECU)	Fresh and processed foods	X			X		X		50%
	Clothes and shoes		X		X		X	X	67%
	Renewable energy				X				17%
	Metal-mechanics			X	X	X	X		67%
	Technology			X					17%
	Vehicles and parts			X	X		X		50%
	Construction			X	X	X	X	X	83%
	Percentage	7%	7%	29%	43%	14%	36%	14%	

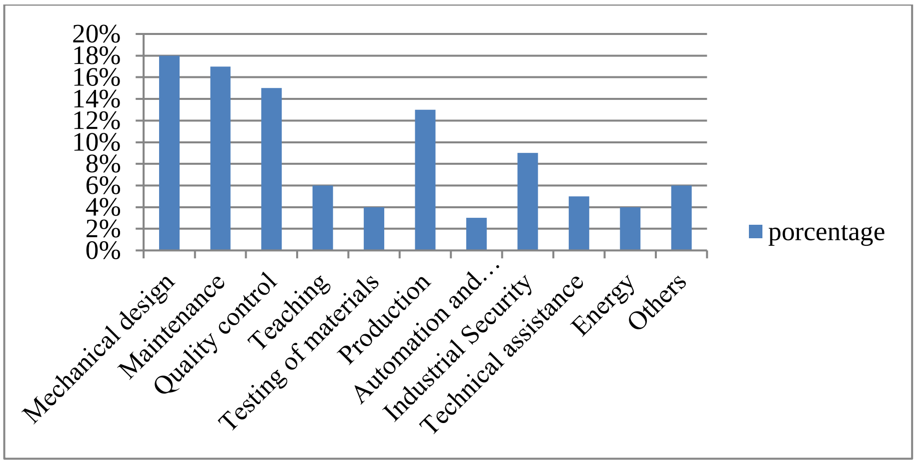

Fig. 3: Specific Area in Mechanical Engineering and Graduation Competition.

Table 3: Specific Area in Mechanical Engineering and Graduation Competition

Area of professional action	
Mechanical design	
Graduation competencies	Create mechanical elements, machines, and structures by innovating and/or adapting equipment to meet the needs of society and industry, using national and international technical and anthropometric standards.
CDIO	
CDIO activities	Conceive: searching needs, identification, and formulation of the problem, ethics, moral, social responsibility, communication, knowledge of regulations, reality of Engineering in the industry. Design: establish design parameters, design conceptualization, pre-design, final design. Implement: detail engineering. Operate: Final project and budget.

Identifying soft skills is a complement to the proposed methodology, to obtain efficient professionals for the knowledge society, in which information can be improved with the performance in the workplace according to the position appointed.

This methodology establishes the adaptation of the CDIO standards with the socio-productive reality of the country and specifically of the central zone. It is based on plans and agendas of local and national development, through graduation competences and learning achievements that are proposed as: knowledge, abilities and skills to be developed in the different subjects of the curriculum of mechanical engineering. The professional academic impact areas are defined and established as: Design, Energy, Materials and Production Management, as can be seen in the example of Table 3 where one of the engineering training areas is indicated as an example.

4. Discussion of results

The proposed methodology allows establishing an academic project focused on the resources developed from the graduate competencies in engineering. These resources promote a curriculum organized around disciplines that support each other and that are intertwined with learning experiences related to inter and intra personal skills developed in the academic-industrial field, in the manufacture of products, processes and systems, managing a response to the socio-productive needs of the country.
The application of the CDIO standards generates a series of resources that can be adapted and implemented to achieve the professional profile of the Mechanical Engineer. Based on these resources, it has been determined that of the standards proposed by CDIO, 2, 3, 5 and 7 are applicable. In these, the description, foundation and rubric for the evaluation of the proposed methodology are clearly identified. It also considers the graduate competences and learning achievements that were obtained in the curricular redesign proposal enclosed in the following standards:

- 2: Learning Results have allowed identifying the knowledge, skill and attitude that a mechanical engineering student should have, reflected in the Silabo of each of the subjects that are considered in the curricular redesign, learning achievements linked to technical and disciplinary knowledge.
- 3: Integrated Curriculum includes the learning experiences that lead to the acquisition of personal skills intertwined with learning the knowledge of the discipline and application in engineering.
- 5: Design-Implementation Experiences where the students consider designing, implementing and conceiving integrated to the design-implementation of the curriculum providing diverse opportunities to establish links between the technical content that they are learning and their own professional development interests.
- 7: Experiences of Integrated Learning that take into account the integrated learning experiences that promote pedagogical approaches to know and know-how, considering problems of professional engineering in contexts, where they coexist with disciplinary problems in the proposal of new and modern learning scenarios.

The process of evaluation of learning achievements should use a control structure that allows the creation of learning scenarios as indicated in Figure 4. One of the key functions of evaluating the proposed curriculum model is to determine the effectiveness and efficiency of the program in the achievement of the proposed objectives. The evidence gathered during the evaluation process of the program also serves as the basis for a continuous program of improvement.

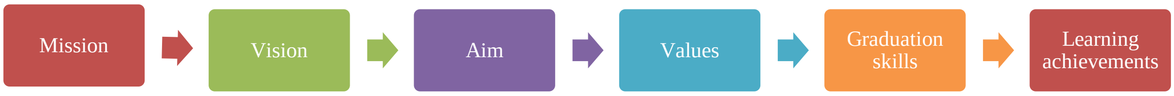

Fig. 4: Control Structure for Learning Achievements

5. Conclusions

This proposed methodology for the redesign of curricula in mechanical engineering has required integration strategies, demanding coordination and collaboration at the industry and academia level. It has involved transversal and longitudinal processes for the determination of areas of knowledge in engineering. By doing this, it has been possible to establish achievements of learning, based on graduate competences in mechanical engineering. In the future, more active teaching and learning methods should be involved, supported on problems and projects that respond to the local and national needs of the country.
The academic offer of Higher Education Institutions, the labor demand and the functions performed by graduates in their professional lives, contribute to the construction of a curricular redesign that has learning achievements according to the local and national reality of the country, based on the graduate competences obtained in this model.
The development of this methodology determines that there must be a discussion, planning and proposal of strategies, policies and projects between industry and Higher Education in the main areas of action of the mechanical engineering in the country.
An evaluation of this concept must be carried out continuously to determine the effectiveness and efficiency of the proposal and the achievement of the objectives. Regardless of the strategy applied by Higher Education institutions, it should be expected that the graduate profiles meet the needs demanded by society and the engineering industry.

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