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Strategies in Engineering Education: Toward A Comprehensive Education

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Abstract

This paper deals with several aspects to be considered in engineering education, highlighting the main challenges faced by universities today in the regional, national and global context. Today's society demands an engineering education that allows the formation of a professional that responds to the demands of new technologies and technological advances. It requires an organization of the educational process and curricular models characterized by being interactive and collaborative, centered on the student to achieve lifelong learning. For engineering education to be in tune with the dynamics of the drastic changes that society is undergoing, it is necessary to consider new teaching options. It is urgent to make permanent planning efforts in engineering education, believing that university education must adapt in the best possible way to technological, economic, and social changes. Within the methodological framework, the actions implemented by four public universities in the last four years are analyzed to diagnose and glimpse the feasibility of establishing new strategies for engineering education. Finally, an integrated proposal is presented with the plan that could be implemented to prepare engineers capable of facing the technological demands of the coming years. These include curricular changes, the use of information and communication technologies (ICT), and alternative and complementary contents so that engineering education can be better and continuously adapted to the dynamics of changes required by society.

Keywords: Engineering education, engineering education, ICT, new strategies.

Introduction

UNESCO, in 2021, focused on engineering to achieve the Sustainable Development Goals (SDGs). This document sets out issues associated with the situation generated by the COVID-19 pandemic, highlighting the interconnected nature of societies and further highlighting that, if engineering is applied effectively, scientific innovations can increase the resilience of humankind. The document also includes engineering innovations and actions contributing to achieving the SDGs globally. Engineering itself must transform to be more innovative, inclusive, collaborative, practical, applied, and responsible [1].

It proposes a new paradigm in the training of engineers at a global level, which involves linking disciplines and is multidisciplinary in its approach. Engineers must assume social responsibility by contributing to a more sustainable and resilient world. For this reason, the engineer's role is fundamental to facing problems such as the insertion of industry in the IV industrial revolution, the supply of clean water and energy, the response to natural disasters, and environmental conservation, among others.

On the other hand, education is the fundamental basis for developing countries, even more so in the so-called knowledge society characterized by privileging intellectual capital. Knowledge as essential capital, knowledge, cognitive and social skills, and abilities as raw materials, collaborative and cooperative work, information management, and applied use of knowledge, among others [2], [3], [4]. Undoubtedly, in the training of engineers, ICTs are essential tools that lead to the development of societies, as they enhance skills and abilities to access information and allow constant and unlimited communication [5].

Globally, engineering professionals have been the central axis of technological innovation processes. Engineering is vital in advancing and implementing information technologies, robotics, biotechnology, and other innovations [6]. The central objective of this research is to delve into a new vision for the training of future generations of students and to provide elements that can serve for the planning of strategies for engineering education.

Considering that the expectation is that accelerated technological advances will be shared in the short and medium term, it is worth asking whether the type of training provided in engineering schools and faculties is adequate. The engineer's role is to make real the principles discovered by science, which initially are only known in their theoretical structure. For various reasons, not all the results of scientific research can be put into practice: the need does not exist, or the investment is too costly. However, the current trend is to apply all actual results of scientific research as a form of technological innovation through systematic engineering application work [7].

The training of an engineer capable of dealing with the technological advances of today's society requires a conceptual framework that considers the nature of knowledge, which response to patterns of development of science and technology and their impact and influence on society. The social studies of science, technology, and society (STS) offer the necessary theoretical framework to consider this aspect [8]. The difficulty of accompanying the dynamics of STS knowledge makes it necessary to consider its inclusion in the curricula and favor better engineering training [9].

A significant challenge that universities must assume in the training of future engineers is implementing and adopting Industry 4.0. In the coming years, industries globally will be highly automated, with intelligent designs, short production periods, and intelligent warehousing, which will allow rapid production and distribution of products. The digital world leads the industry 4.0, which consists of the introduction of technologies directly into the production processes of an organization through sensors and information systems [10][11]. ICT and teaching-learning through software are fundamental in future engineer training [6],[12].

Accompanying engineering education with programming and simulation, on the one hand, allows students to be able to conceive, plan, design, and create software as a tool to change the world, and on the other hand, to develop a series of cognitive skills integrated with the so-called computational thinking [13],[14]. Computational thinking encompasses a series of principles: creativity, abstraction, problem analysis, logical and critical thinking, communication, and collaboration. Virtual reality, robotics, intelligent tutoring systems, and online learning will feature prominently in basic science and engineering education [15],[16],[17].

Regarding the job market, engineers are expected to be able to communicate, interact and work with people from different backgrounds, to be able to become leaders, be ethical, and perform effectively. To achieve this, they must develop skills in communication, teamwork, negotiation, interpersonal relations, management, ethics, lifelong learning, emotional intelligence, and creativity [18].

Engineering education, conditioned by drastic changes, must adapt to innovations, advances, and technological developments. The issue raised in this research is the training of an engineer according to the needs of the environment and how to adapt to technological advances and current trends in education. In the training of the professional, a new approach is assumed that allows the generation of new ways of thinking and acting that are more appropriate to the characteristics of the new times. Such professional training should be oriented towards comprehensive, continuous, or lifelong learning through the adaptation of curricula and the use of ICT [19],[20],[21].

The focus of this work is based on three fundamental elements:

i) That universities must have an adequate technological platform and infrastructure to meet the challenges involved in training an engineer with a comprehensive education. With a digital platform, it is possible to develop a methodology that involves distance or semi-distance interaction in the teaching-learning process.
ii) The professors need to be prepared, in their skills, to assume the challenges involved in incorporating ICTs in the training of engineers in the coming years.
iii) The university has considered making curricular changes so that ICT will naturally be incorporated as a fundamental tool in the training of engineering careers in the coming years.

Based on these and other elements, establish strategies that should be considered in engineering schools to form an integral engineer capable of assuming the challenges of technological advances and future developments.

This work is organized as follows: Section II shows aspects related to the research development and the methodology used. Section III shows the results, which are then discussed in Section

IV. Finally, the main conclusions and references are shown.

Development

In recent years, the companies with the most significant economic impact on a global scale are technology companies, and this is one of the main challenges that university education institutions that train engineers must face. The recommendations that make it necessary to strengthen and encourage engineering studies with a view to the 2030 goals outlined in [1] consider aspects such as:

- The rapid emergence of new technologies is an opportunity for transformation toward new teaching-learning models.
- There is a decrease in the interest of young people in studying basic sciences and engineering careers.
- Migration of engineers to other countries.
- Public policies must consider the need and importance of engineering for sustainable development.
- Engineering innovation is needed to adapt and respond to current global challenges and to achieve the SDGs.
- Engineering is essential for economic progress and the application of new technologies, as well as for the application of science, in particular, to meet basic needs for food, health, housing, infrastructure and transportation, water resources, and energy.

Recently, strategies on how to improve engineering education have been analyzed. It was suggested that teachers and graduates should know to meet the current needs of society [22]. In addition, an adaptation and modification of the curricula focused on more excellent linkage with the company, promoting cognitive, self-leadership, interpersonal, and digital competencies, in addition to the comprehensive training of students. Then, taking into account the national and international environments, it is suggested that, in the curricula, the ability for lifelong learning and multidisciplinary training should be incorporated.

The influence of information technology in different fields at the end of the 1990s generated a new vision for disseminating and imparting knowledge. Due to the advancement of ICT and the role that engineers play in social development, it is necessary to pay attention to their comprehensive training and development in the future. The growth and industrialization of industry 4.0 are essential factors of progress in the coming years, and engineers are called to play a vital role [2],[5].

The university has the challenge of leading the transformation processes of societies and creating, reformulating, and adapting to changes according to the reality of each country. The conception of engineering education in the new global conditions requires a transformation of the educational model since the development of engineering education is defined by its relationship with the degree of scientific and technological development and progress in a given country and at a global level.

The teaching-centered model must be replaced by one that places greater emphasis on learning [23]. The teacher goes from being a transmitter of knowledge to guiding and helping to build schemes of thought, understanding and interpretation that allow transforming information into knowledge, i.e., processes that teach learning to apply.

Universities must make the necessary transformations for innovative teaching, with more profound learning and responsibility for forming an integral graduate. With suitable theoretical and practical bases, engineering education must project educational models that provide the epistemological, methodological, and practical foundations to achieve the learning required in the coming times. The curricula cannot ignore what the regional, national and global work environment imposes on the university.

Some authors analyze the need to train engineers with a broad and flexible knowledge base, with skills and attitudes that enable them to fulfill their social responsibilities, challenges faced by higher education institutions that train engineers [3],[6],[34]-[36]. Engineering requires an increasingly multidisciplinary, comprehensive, scientific, practical, social and humanistic academic training of professionals. This will be possible to the extent that their scientific, technological, ecological, social, ethical and other training is improved.

This leads to consider the elements to achieve the formation of an engineer with comprehensive training, adapted to the technological advances of the present and the future, using current strategies such as ICT in their training. In such a way that the profile of the graduate engineer can be blended with current teaching-learning strategies.

For the development of this research, surveys-interviews were implemented based on the following aspects in Table 1:

Table 1. *Template of questions structured for surveys and interviews*

Aspects of the survey of managers and professors of universities offering engineering degrees:
In recent years, how has the institution you lead been prepared for new trends and technological advances to take on the challenges involved in training an engineer to meet technological advances, industry 4.0, and its context.
How has the institution you lead been prepared for the new trends, perhaps accelerated by the confinement and restrictions of the pandemic covid 19 already. Several universities have entered e-learning, and b-learning occupied spaces for new trends at the university level.
The Covid 19 pandemic forced an abrupt and unexpected migration to a distance education model without being prepared to assume it.
Distance education units existed in universities before the pandemic. We are reviewing what actions are taken by engineering schools in some of the significant universities in several countries regarding training and modality.
The functions of the engineer must stop being oriented toward the assimilation of technologies to solve problems related to the installation, operation, and maintenance of production systems.
Preparation to take on the technological challenges that the engineer's training will require in the coming years.
Platform and equipment infrastructure required for multimodality.
Training plans for their professors to take on the challenges required by multimodality.
The new challenges imply changes in the contents and curriculum of engineering studies.
Teaching laboratories in engineering careers lead to simulations of laboratory practices, or they must be face-to-face.
The University prepares its professors, but the students what is offered to them.
Plans to reformulate the introductory courses of the engineering schools.
They have platforms and internet suitable for a semi-face-to-face, distance, or mixed modality.
Implies shortening, increasing, or reorienting the contents of the primary cycle subjects.
The curricula remain the same, reorienting how the contents are taught.
The library as we know it is no longer practical and now relies much more on online content.
Strengths to prepare an engineer according to the demands of the fourth industrial revolution or industry 4.0

Methodology

It is proposed to diagnose if the universities are prepared and have the technological capabilities to train engineering graduates with the knowledge and tools to face the technological challenges of the coming years. The work is non-experimental, exploratory research because information gathering tools will be used, such as surveys and interviews applied to directors and professors of four universities that teach engineering careers.

On the other hand, the research is documentary since data from existing sources in the literature will be investigated, interpreted, and presented.

Results

Engineering education requires changes to have a graduate with the skills to perform in a work environment dominated by technology. It requires a model whose objective is to have a comprehensive education graduate with the ability to access and implement knowledge. Engineering students must be prepared to face the technological challenges of the present and the future [25]:

1. Independent learning, complementary to what is taught in the contents of their subjects. It implies reviewing articles in scientific journals to keep updated with technological advances in their training areas.
2. Critical and creative thinking for understanding, approaching, and solving problems.
3. From their training stage, develop skills for interpersonal work and teamwork, and ease of communication.
4. Analytical and critical. In addition, it strengthens their capabilities for integrating knowledge from other areas in their studies.
5. Adaptation to changes, developing skills, strategies to adapt to changes, new trends, innovations, and technological advances.

The following are the survey results and interviews conducted at four public universities offering engineering degrees. University 1 only trains engineers in electrical, mechanical, metallurgy, electronics, and industrial engineering. University 2, in addition to engineering, trains engineers in basic sciences. Universities 3 and 4 train industrial, electrical, mechanical, and civil engineers.

A total of eight managers were interviewed, two from each institution. In addition, 139 professors from the four universities were interviewed: 27 in physics, 34 in chemistry, 37 in mathematics, and 41 in engineering. Tables 2, 3, and 4 show the results, according to the interview surveys, for the diagnosis of the last four years

Table 2. *Investment, preparation and adaptation to the use of ICT for distance education in engineering careers in a public university 1.*

Year	Advances in the use of ICTs and curriculum change
2019	-Few notions of distance education -There was a platform to migrate to this model, but the contents of the subjects were not loaded. -Little knowledge of Distance Education (DE) at the student and teacher level. - Some individual efforts indicate a small number of teachers with Moodle platform training. - Face-to-face labs
2020	- COVID-19 pandemic forces migration to distance education options. - Managers begin to think of DE as an alternative. - Increased individual efforts of teachers for training on Moodle platform. - External domain hired to host contents. - Content on the platform is strengthened. - Training courses on DE increase. - No curricular changes are foreseen.
2021	-Increase in the number of students compared to previous years. -Practically, DE is adopted as an educational model. - Online labs without a defined structure, depending entirely on the teacher. -Basic science subjects are all online. -Internships suspended.
First semester 2022	- A semi face-to-face stage begins. - In spite of this, there is a platform, although with flaws in the contents, moderately complete as an alternative. - Changes in the curricula are being considered. - On-site laboratories.

Table 3. *Investment, preparation, and adaptation to using ICT for distance education in engineering careers in a public university 2.*

Year	Advances in the use of ICTs and curriculum change
2019	- Knowledge of distance education. - There was a platform with the contents of most of the subjects loaded. - Several teachers relied on the platform to teach their classes. - Several teachers with training in Moodle platform. On-site laboratories.
2020	- The COVID-19 pandemic forces us to increase the number of subjects on the platform for the distance education option. - Implemented as an alternative due to the restriction of face-to-face classes. - The platform is strengthened and updated. - 70% of the subjects are taught through the platform. - Subjects that include laboratories are not opened. - Basic science subjects are all online. - Internships suspended.
2021	- The number of students has increased with respect to previous years. - 70% of the subjects are open to distance learning. - Courses with laboratories, taught entirely online, are opened. - No curricular changes are planned. - There is a platform to offer distance or semi face-to-face training for engineers. - 80% of the professors are trained to deal with DE.
First semester 2022	- A platform is in place to offer distance or blended learning training for engineers - 80% of the teachers are trained to deal with DE.

Table 4. *Investment, preparation, and adaptation to using ICT for distance education in engineering careers. The results for public universities 3 and 4 are very similar*.

Year	Advances in the use of ICTs and curriculum change
2019	- There were plans to alternate face-to-face classes with DE. A platform was available, although classes were face-to-face. - Teachers and students trained in DE.
020	- COVID-19 pandemic forces focus on the Distance Education option. - Managers begin to think of DE as an alternative. - Institutional courses for teachers for training in Moodle platform increase. -The platforms are strengthened by adapting the contents. -DE courses for teachers increase. -It has its servers. -Economic resources are invested in strengthening its platform and training its teachers in DE. -Subjects are all online.
2021	-The number of students increased from previous years. -Practically, the DE s adopted as an educational model. -Progress is made in curricular changes.
First semester de 2022	Presence begins. - There is an optimal platform, although with flaws in the contents, moderately complete as an alternative.

From these results, projecting the profile of a graduate for 2030, we infer the need to introduce urgent changes in the engineering curriculum, among which we can suggest [21]:

- Strengthen training in basic sciences: mathematics, physics, chemistry. Another essential component is the use of a programming language, using commercial software, in the teaching of classes. It is common in the literature and articles related to the solution of problems in basic sciences using intelligent computing techniques [12],[13],[14],[26].
- Specific training in the branch of engineering chosen by the student with sufficient quantity and quality of knowledge to learn to apply. Necessary complementary training in areas of economics, languages, and STS.
- The learning platform or environment should be designed in such a way as to include strategies to expand the basic knowledge that strengthen the intellectual development of the student. It includes support material, real situations videos, and processes simulation, among others. It develops the ability to face reality thoughtfully, critically, and constructively [27].

The above leads to propose elements and strategies that should be considered in order to adapt the education of students in engineering careers:

3. 1 Educational model

- Transversal training, whose difference in the training is with a certain number of subjects that mark the orientation of the particular engineering. The engineer of the fourth industrial revolution must know about heat transfer, fluids, electricity, and management.
- To enter a globalized world, the engineer must be prepared to think and face new problems that appear in his work.
- Universities should invite professors from foreign universities to strengthen the teaching staff in the training of the engineer of the future of the coming years.
- Include STS studies in the training of engineers and high-level English as an additional language.
- New content and adaptation of the existing ones to the new educational trends.

It is essential to consider the use of technologies in student training, oriented towards the fourth industrial revolution, soft skills, and what and which contents should be included in the curricula.

3.1.1 Pre-university

Include university initiation courses (UIC) with six fundamental modules: Physics, Chemistry, Mathematics, Engineering Sciences, English, and ICT (Table 4).

Modules for the university initiation course.

University Initiation Courses (UIC)	
Modules	Percentage number of hours (%)
Mathematics	30
Physics	30
Chemistry	20
Science and engineering	8
English	6
Introduction to ICT	6

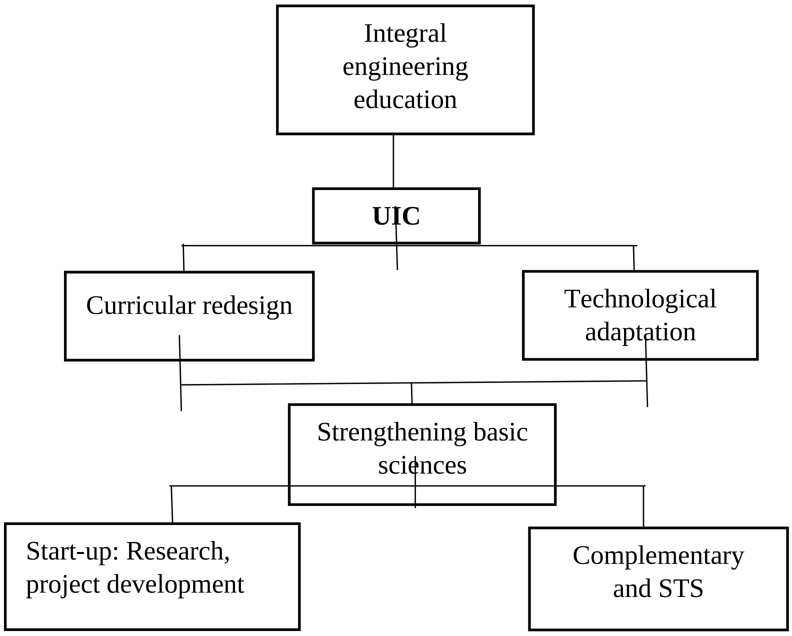

Figure 1. *The diagram shows the strategies to be followed in training engineers in the coming years in an environment dominated by technological advances*.

- The introductory courses should be reoriented and strengthened with the essential elements that point to the specific engineering and a complementary component of other engineering, administration, management, and humanities.
- An engineer with a research component, project development, bibliography management, and scientific articles related to his career.
- An academic tutor for the integral formation
- Create a culture for the management of references to keep up to date with technological advances in their competence areas.
- The STS component for an engineer with social sensitivity who can apply knowledge to benefit society.
- Internships in industries where the engineer has contact with real problems.
- Changes and adaptation to continuous technological advances.

It is necessary to incorporate the STS component in engineering careers in universities since it is based on the relationship between science, technology, and society. Such a conception drives a new conception of engineering, which is more deeply integrated with society, underpinning progress towards sustainable development [1]. It has imposed a new challenge on science and technology. This new model, in turn, is deeply related to the new way of understanding the science-technology-engineering-industry relationship in a complex and changing world. For these reasons, it is necessary to develop in students the capacity to understand the world they will live in and the challenges that engineers will have to face, as well as to orient the social value of engineering.

It makes it possible to define the functions to be performed by those responsible for training engineers in university teaching institutions.

3.1.2 Universities

- Research plans capable of gathering ideas, problems, and adequacy in teaching and learning different areas of knowledge related to technological advances and developments.

- Develop strategies that contribute to promoting multimodality and the implementation of ICT in educational models [27].
- Research and intervene in the design, development, and evaluation of the curriculum in engineering careers.
- Educational strategies: ICT, curriculum updating, new teaching models for laboratories: virtual and face-to-face [28].

3.1.3 The teacher

As for teachers, they should be updated and prepared to train students in creative thinking, teamwork, and emphasis on problem-solving [18],[19]. It is essential to make graduates and teachers more competitive (research activities) to contribute to developments for the benefit of society.

Evaluate by projects, as a way to encourage research activities [31].

- Tutor teacher at the beginning of the course
- Teaching classes: e-learning, b-learning, support of complementary material, videos, synchronous, asynchronous [27],[28],[33].
- Encourage research and bibliographic review of scientific articles from the first semesters.
- Training in basic sciences, Chemistry, physics, and mathematics with engineering applications and software management problems.

Libraries as we know them are no longer critical, with the migration not to digital libraries but the information world of the network. The teacher must be a filter, an intermediary between the student and the volume of information available, recommending the material and videos most adapted and appropriate to their training.

3.1.4 Graduate

Experience in handling laboratory equipment, ability to research, lead research groups, and create the culture for managing references to keep updated on technological advances in their competence areas.

Discussion of Results

The revision of engineering careers should emphasize basic knowledge, mathematics, language and communication, and include subjects in the training area, as well as activities that allow the student to interact with industry, especially in the last stage of the career. The goal is to improve the academic level through changes and adaptation of the curricula and the implementation of ICT in the teaching-learning process.

More than an imposition, it is an imperative need for universities to adapt their contents to the new trends and technological advances in their teaching models and curricula for the formation of an engineering professional, capable of facing the challenges that a globalized environment requires [30].

- An education that has at its center the individual, his or her learning and the integral development of his or her personality.
- An educational process in which the student has the leading role under the orientation, guidance and control of the teacher.

- Scientific and global contents that lead to instruction and training in knowledge and skills to compete with efficiency and dignity and to be able to act consciously and critically in decision making in an ever-changing context.

To achieve the above in engineering education requires:

An educational model focuses on the student, what he/she needs to learn, and the technological trends and innovations teaching under an interactive and collaborative model. Using methods that allow the development of research skills and problem-solving skills [23]. In addition, include activities that allow the development of computational thinking [12]. Implementing artificial intelligence and programming languages in the career needs a paradigm shift. Not only because it increases their knowledge of technology; but also because it allows them to delve into the solution of application problems in basic science subjects [32], [37], [38].

Conclusions

The training of engineers today requires solid scientific and technological education. To achieve this, universities must develop open curricula with a broad and flexible profile through their training processes. They must be dominated by new and innovative learning to contribute to the preparation of updated, creative, and participative professionals in their environment. Therefore, knowledge of the specialty is necessary, as well as skills and abilities to make decisions and assume social responsibilities. All these elements would allow the development of a competent professional capable of interacting and responding to contemporary society's economic, environmental, and scientific-technological problems.

The results presented in this work are intended to contribute to planning several aspects required for the training of new engineers to be in accordance with technological and social changes. It is necessary to implement mechanisms for the university to train engineers who contribute to developing new clean, appropriate, and self-sustainable technologies for the welfare of society.

The actions proposed in this work are oriented toward the future of engineering education in the short term. Public universities are not equally prepared to assume the challenges of change in teaching strategies in engineering education. It is necessary to act in the short term since the results in terms of their social impact will possibly be seen in the next 15 years due to the time it takes to approve this type of transcendental change in the educational models in public universities.

For graduating engineers to have an early insertion in the productive systems, the new generations must be prepared for the labor market through comprehensive training. Engineers' learning must be permanent, and they do not think that their training ends when they obtain their university degree but that their training is permanent and lifelong. An excellent way to keep updated is through continuous postgraduate training and review of scientific articles.

Promoting the mastery of foreign languages and including STS studies in the curriculum is necessary. It is crucial to encourage professors to obtain master and doctoral degrees abroad. It is recommended to hire foreign professors with the intention that engineering students become involved in research and development projects and in international innovation networks in which these professors participate.

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